APPLIED GEOLOGY

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BY

J. V. ELSDEN B.Sc.(Lond.)

PART I

WITH NUMEROUS ILLUSTRATIONS

PRICE FIVE SHILLINGS

LONDON
"THE QUARRY" PUBLISHING Co LTD
5 ARUNDEL STREET STRAND WC
1898

Butler & Tanner,
The Selwood Printing Works,
Frome, and London.

PREFACE TO PART I

CIRCUMSTANCES have made it necessary to publish the earlier chapters of this work separately, while the later portion is still appearing in the pages of the *Quarry*.

To those who may read the following pages I would, therefore, point out that these preliminary chapters scarcely give an adequate idea of the scope of the completed work.

The scarcity of books dealing with the practical side of geology has been long felt; but it will be for others to judge how far this attempt to supply that want may have been successful. My difficulty throughout has been an attempt to combine as much geology as the practical man should know with as much practical detail as should interest the geologist.

I lay no claim to any originality, and have freely used all available sources of information as to the facts recorded in this volume. A more complete acknowledgment of these sources will be published at the conclusion of the work.

J. V. E.

STORRINGTON, 1898.

CONTENTS OF PART I

CHAPTER I

Aim and Scope of the Subject—Method of Treatment—Geological Surveying—Outcrops—Thickness of Strata—Maclaren's Rule.

Aim and Scope of the Subject.—Geology, in its practical application, appeals to all who are concerned in the development of the mineral resources of the earth. Its aim is directed, in the first place, to the discovery of useful minerals and to a correct estimation of their quality, quantity and accessibility. Upon the accuracy of this knowledge depends, in a great measure, the success of industrial ventures connected with the mineral productions of the globe, as well as the surface capabilities of a country as regards improvement by agricultural or engineering schemes. To the agriculturist, the land valuer, the architect, the engineer and the manufacturing chemist, to all, in fact, who make use of the raw materials supplied by the mineral kingdom, a practical acquaintance with the principles of geology is essential to the highest degree of success. The agriculturist derives assistance from geology, not only in ascertaining the nature and properties of the soil overlying the rocks beneath, but also in determining to what extent that soil is capable of improvement by admixture with the mineral materials, whether chalk, sand or clay, which the neighbourhood affords. The land valuer cannot neglect the consideration of valuable minerals which either are or may be found in workable quantities on an estate, the after discovery of which has often led both to an enormous increase in the value of property, and also not infrequently to expensive litigation. The architect must be acquainted

with the durability of the different building stones, and their adaptation to the various purposes which he has in view. The engineer is confronted at every turn by geological problems upon which the success or failure of his schemes depend; while the manufacturing chemist, whose raw materials are of a mineral nature, must keep a watchful eye upon the discovery of fresh sources of supply, and upon new methods of diminishing the cost of his productions.

But if geological knowledge is necessary to so many different arts and sciences, how much more is it essential to the miner and the quarryman who are directly concerned in the extraction of useful minerals from the earth's crust? It is not easy to explain why this necessity is not more fully recognised, unless it be due to the fact that the majority of geological text-books are so laden with theory that the practical aspect of the science is either lost sight of or altogether ignored. Not that theory should be despised as altogether useless to the practical man. Theory generally precedes practice, and if the converse has often been true in the case of many geological discoveries, this is due in a large measure to the fact that geology as a science is of more recent date than the arts of mining and quarrying. If we balance the successes of our mining and engineering forefathers against the many failures which have resulted from ignorance of geological phenomena, we should find overwhelming proof of the assistance which is to be derived from a proper acquaintance with the science of geology. As examples of the value of combining theory with practice, it is only necessary to remember the splendid geological deductions which led up to the recent discovery of coal in the south-east of England, or the successful search for phosphate deposits in the cretaceous rocks of France, which was based entirely upon their analogy with those of England. Even a knowledge of fossil species becomes helpful in the identification of geological horizons in widely separated localities.

Treatment of the Subject.—It will be the object, therefore, of the following chapters not so much to multiply the already long list of geological text-books as to supplement these by bringing into greater prominence those portions of geological science which bear upon the daily routine of the practical man. In a subject of such wide extent some acquaintance with the more elementary portions of the subject must necessarily be assumed. It is perhaps unfortunate that most of the practical problems involved in the relations of dip, outcrop and strike are of a mathematical character, but wherever possible solutions will be given by graphic construction, as well as by mathematical formula. In this way it is hoped that these important problems will be brought within the comprehension even of non-mathematical readers.

Practical geology is so intimately connected with chemistry that some knowledge of this science must also be assumed in many of the following chapters; but here again an effort will be made to present the subject in a manner which will be equally intelligible to the non-chemical reader. Much important information can be gained by simple chemical tests, without in any way intruding upon the domain of the professional chemist.

As to the order in which the subject will be treated, several courses have been adopted in existing manuals, each of which has obvious merits and defects where so many interests have to be considered. But there are certain principles which are of general utility, whether to the engineer, the miner, the quarryman or the agriculturist. These will be first discussed, with the object of preventing unnecessary repetition.

Geological Surveying.—In the first place it is necessary that all possible geological information should be accurately laid down upon a map. No matter what may be the ultimate object in view, whether it be the opening of quarries or mines, the construction of roads or railways, the

improvement of estates, or the acquisition of water supply whether the scheme be large or small, a geological map is the first essential to success. The maps already published by the Geological Surveys, not only of the British Isles, but also of many other countries, are admirable for this purpose, but even these often require supplementing with additional details. It is impossible, for instance, to show adequately upon the same map both the surface soils and the underlying rocks. In our own country this difficulty is overcome by the publication of two distinct sets of maps; but these being on a scale of one inch to a mile, it is not possible to include the minor details necessary to a good working map. For many countries, also, such maps are not obtainable at all, and the investigator is driven to the necessity of undertaking a geological survey for himself. This involves a good deal of patient and detailed labour, which, however, is amply repaid by the more accurate knowledge of the locality which is thus obtained, and by the greater certainty with which the occurrence of valuable minerals can be predicted.

Of course an accurate topographical map on a fairly large scale must form the basis of the survey. A scale of six inches to the mile will be found suitable for large areas, but for smaller areas a scale of twenty-five inches to the mile, such as the parish maps of our own Ordnance Survey, will be preferable. In foreign parts, where no accurate maps exist, this topographical map must be prepared before the geological survey is attempted. Contour lines should in all cases be shown, for which purpose an Abney's Level will be found a most convenient instrument, as it can be used not only as a level, but also as a clinometer. A Watkin Mirror Clinometer is equally serviceable for contouring, but not of such service in the subsequent operations. It is quite a mistake to conclude that fairly accurate maps require an expensive equipment. Sketches made with plane table or prismatic compass, if care is taken, are

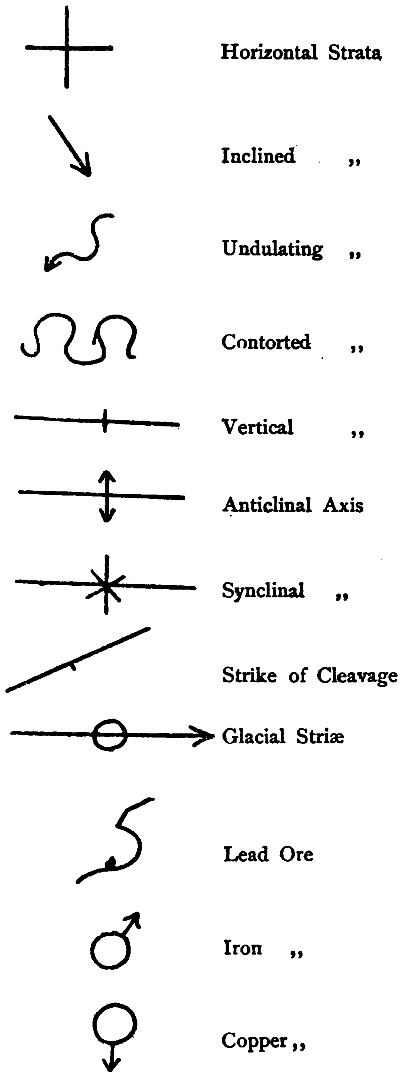
Horizontal Strata
Inclined ,,
Undulating ,,
Contorted ,,
Vertical ,,
Anticlinal Axis
Synclinal ,,
Strike of Cleavage
Glacial Striæ
Lead Ore
Iron ,,
Copper ,,

FIG. I.

of sufficient accuracy for most purposes of practical geology. But a correct topography is indispensable to the accurate mapping of the boundary lines of geological formations, which otherwise become distorted and untrustworthy. No better examples of rapid topographical surveying with simple instruments could be given than the methods employed by military men, for fuller details of which the reader is referred to the numerous existing text-books on the subject. It would carry us far beyond the limits of the present articles to discuss here the methods of mapping and we must therefore assume for the present purpose that a map, on a sufficiently large scale, is at hand.

The next step is to lay down upon the map the boundary lines of the various geological formations, as well as all available information as to the angle and direction of dip. To avoid crowding the map with written explanatory notes, it is useful to adopt symbols, of which the following have been found convenient by the Geological Survey of Great Britain (Fig. 1).

The actual work of mapping the various rocks exposed at the surface is only accomplished by systematically traversing the ground, taking advantage of every natural exposure of the underlying rock. For this purpose brooks, coast lines, ravines, hillsides must be carefully examined, and the nature of the exposed rock noted. In the accompanying diagram (Fig. 2) the left-hand portion is intended to represent the map of a district upon which a geological survey has been commenced. It will be seen that the evidence of the nature of the rocks is very fragmentary, and has been chiefly obtained along the course of the streams. There are large areas, however, in which no information whatever is available: for a distance of several miles, it may be, the rocks are completely covered by vegetation, or by a thick coating of superficial deposit of sand or gravel. In spite of this, however, we have to fill in the boundary lines of each formation and complete the

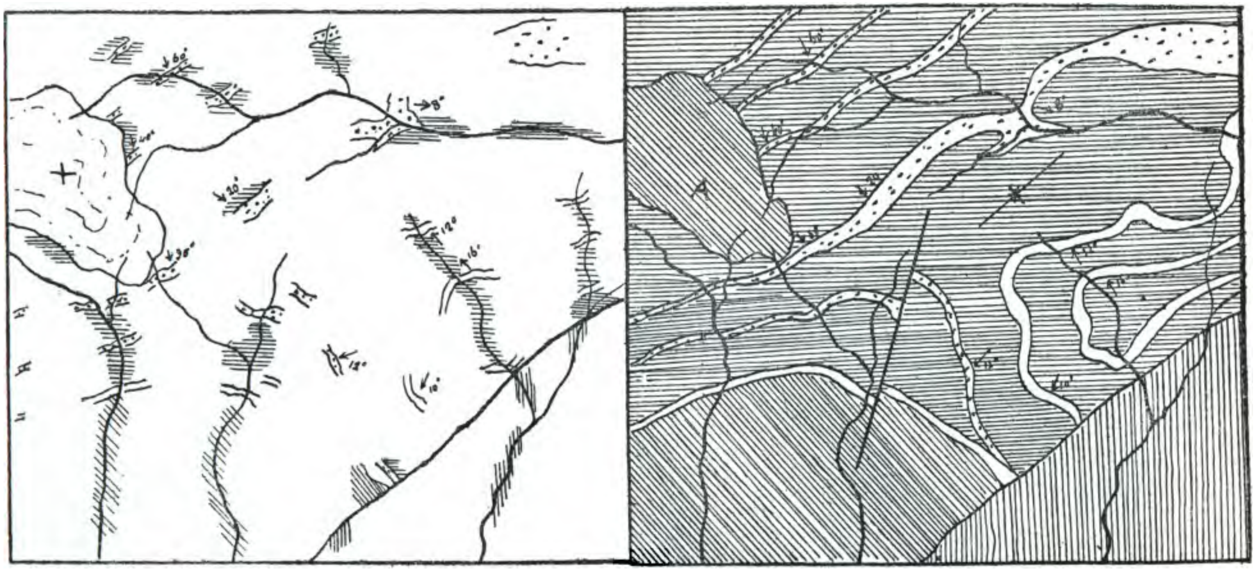

FIG. 2.

maps as shown in the right-hand portion of Fig. 2. Some help may have been afforded by carefully examining the nature of the soil or the character of the vegetation. The stones lying loosely on the surface may assist. Angular fragments of rock, especially on hillsides, may be traced to their source, or a change in the character of such fragments may indicate the proximity of a boundary line of two different beds. A little practice will soon enable the investigator to accumulate upon his map sufficient evidence for the correct interpretation of apparently concealed areas, and this brings us to the next stage in the process, the tracing of boundary lines and outcrops.

Outcrops.—The area occupied by the exposed surface of a rock is bounded by two lines, one of which, coinciding with its upper edge, is called the "*line of outcrop*"; the other, coinciding with the lower edge, is called the "*line of boundary.*" The term *outcrop*, as generally employed, refers to the whole area between these two lines. It is obvious that this area will vary considerably with the inequalities of the ground, and great assistance is derived from a study of contours in mapping outcrops across concealed areas. Referring again to the left-hand portion of Fig. 2, we see that there is a great deal to be done in joining up the broken lines, afforded by the fragmentary evidence obtained by traversing the ground, before the varying breadth and direction of the different beds can be defined as on the finished map shown opposite. Now the breadth of the outcrop depends upon three conditions: the actual thickness of that stratum, its angle of dip, and the slope of the ground.

Let us first consider the last condition, that is the relation of the outcrops to the contour lines. For this purpose the following rules are of great assistance, and should be carefully remembered:—

(*a*) If the strata are horizontal, their boundary lines must coincide exactly with the contours; so that if one point only can be ascertained with certainty through which

the boundary line passes, the boundary must follow the same contour so long as the bed remains horizontal. In this way the horizontal strata, marked *A* in Fig. 2, may have been accurately mapped with perhaps only a single exposure of the beds.

(*b*) When the strata are vertical, surface irregularities make no difference on their outcrops, which run in straight lines across hills and valleys alike. In this case it is sufficient to determine two points on the boundary, the intervening space being filled in by the straight line joining these two points. This case occurs especially in mapping intrusive dykes.

(*c*) The boundary lines of strata dipping towards a hill

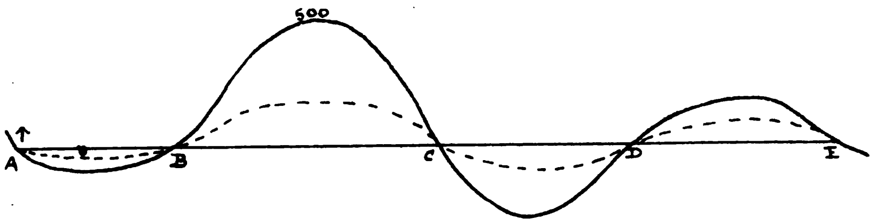

FIG. 3.

are *less winding* than the contours. This will be evident if we consider that every point *on the line of strike* at the same level as any one point through which the boundary line is seen to pass, must also be on the boundary line. Thus let *A* (Fig. 3) be a point on the boundary line of a stratum, situated on the curved contour marked 500, and let the strike of the stratum be in an *E* direction along the line *AB*; then we know that the points *B*, *C*, *D* are also on the line of boundary. We therefore connect these points by *flattening* the contour in proportion to the dip of the stratum, always remembering that the steeper the dip the more nearly does the line of outcrop approximate to a straight line, *i.e.* the line of strike; while the less the dip the more nearly are the beds horizontal, in which case their

outcrops would exactly coincide with the contour lines. This is a most common case, as strata most frequently dip into a hill. In Fig. 4 an attempt has been made to illustrate this principle by means of a model, in which the broken lines represent contours, and the thick lines are

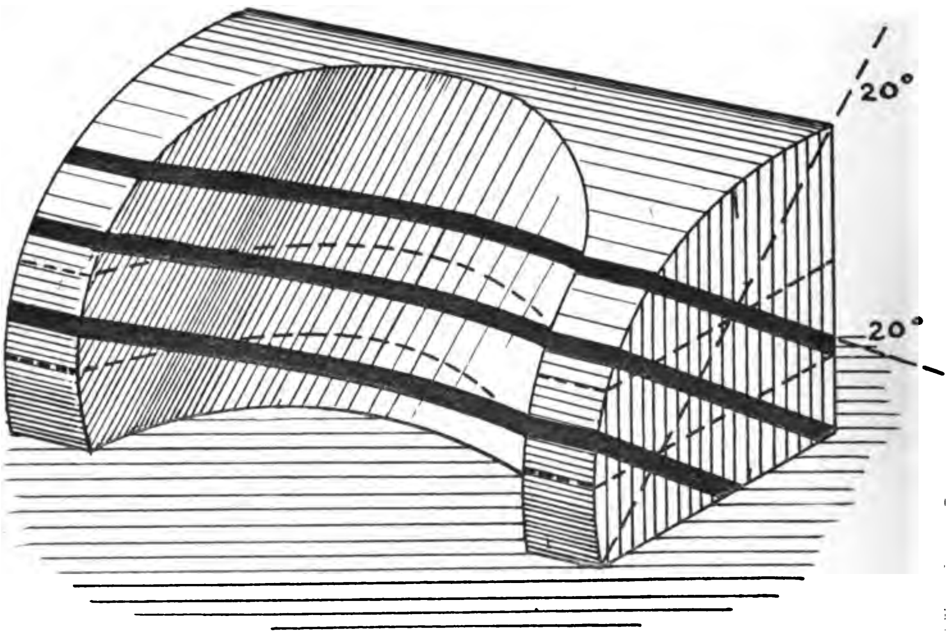

FIG. 4.

the outcrops of seams cropping out in a valley on a hill-side.

(*d*) The boundary lines of strata dipping from a hill are *more winding* than the contours. Three cases may occur, distinguished by the form of the *V*-shaped outcrops in the valleys. When the dip of the strata is less than the slope of the valley, the *V*'s point upwards, the newer strata ap-

pearing *higher* up the valley than the older beds. This is illustrated in the diagram, Fig. 5, where the dip of the strata is 20°, and the slope of the valley 30°.

When the dip of the strata is equal to the slope of the valley, the boundary lines run down the flanks of the valley,

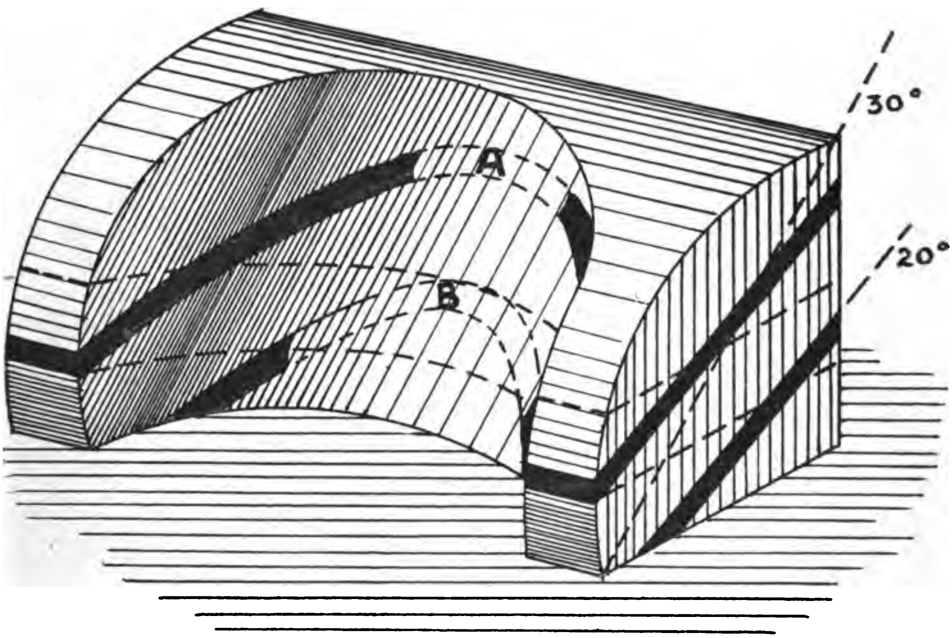

FIG. 5.

cutting the contours at right angles (Fig. 6). When the dip of the strata exceeds that of the slope of the valley as in Fig. 7, the boundary lines are reversed as regards the contour windings, the *V*'s pointing downwards, and the newer strata appearing *lower* down the valley than the older beds.

As the angle of dip still further increases, the *V*'s open

out into straight lines in proportion as the strata approach the vertical.

From the above considerations we see how important is the relation between contours and outcrops, and what valuable assistance may be derived from contours in the pro-

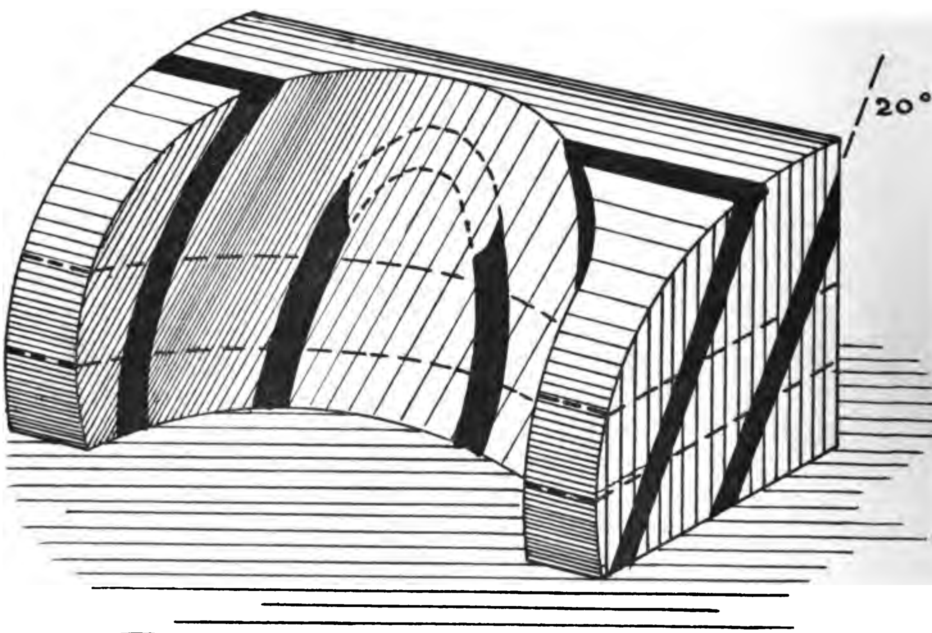

FIG. 6.

cess of geological map-making. A further practical bearing of this relation has already been pointed out in the text-books. Seeing that the dip of strata may, and often does, change rapidly in a small area, it is possible that the conditions shown in Figs. 5, 7 might occur in neighbouring valleys. A miner, having explored a valley (Fig. 5), may have sunk a vertical shaft below the seam *A* into the lower

stratum *B*. Passing on to the valley (Fig. 7), and two seams cropping out there also, he might attempt the same plan of operations in the hope of reaching the lower seam by a shaft from the upper one. It is obvious, however, that a vertical shaft from *B* (Fig. 7) could never penetrate

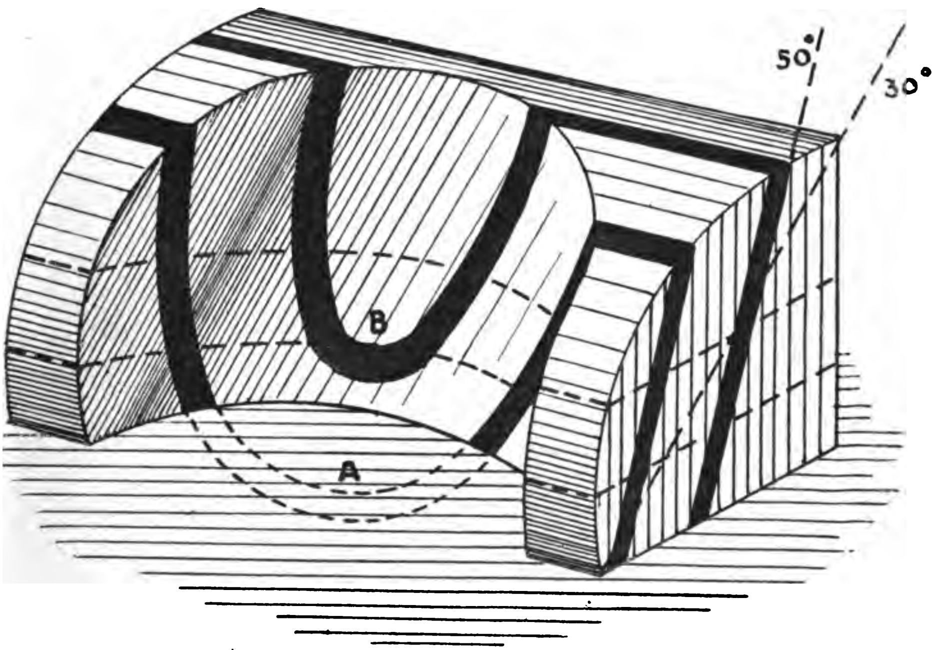

FIG. 7.

A, which is really a newer bed, although it crops out lower down in the valley.

Thickness of Strata.—The breadth of an outcrop is no guide to the thickness of a bed. A thin seam in a nearly horizontal position would cover a larger area than a thicker formation dipping at a high angle. Neither must it be inferred that a diminishing width of outcrop implies a

thinning of the bed, unless it is known that the dip has not changed, and that the surface of the ground presents no marked inequalities. In estimating the thickness of strata, the angle of dip must first be measured in a direction at right angles to the strike. This is not always possible, but it will presently be shown how this dip may be calculated from any two observed dips in any direction whatever.

It need scarcely be pointed out how important to the

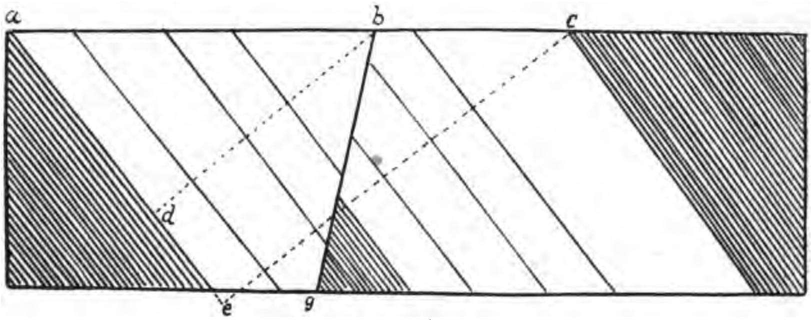

FIG. 8.

practical man is the question of the thinning out of beds, so that the determination of the thickness of any seam is a constantly recurring problem in applied geology. This may be done mathematically by multiplying the breadth of the outcrop, in a direction at right angles to the strike, by the sine of the angle of true dip. Thus in the diagram (Fig. 8) the thickness of the strata from *a* to *b* is *b d*, which is evidently *ab* sine *bad*. It is important that the absence of faults should be first ascertained, or the thickness may be greatly exaggerated.

In the above diagram (Fig. 8) a fault is shown at *bg*, causing a repetition of the strata, and an increased width of outcrop. Thus, in the above case, a thickness *ce* might be found, instead of the true thickness *bd*.

It is readily seen that if the above diagram were drawn to

scale, and the angle of dip plotted accurately with a protractor, the thickness *bd* could be measured off directly without the aid of trigonometry. Such graphic methods are greatly to be recommended in the solution of geological problems, and, as will be presently seen, many complicated calculations are much simplified by this means.

For those, however, who may desire a still more ready method of estimating thickness in the field, Maclaren's Rule may be used with fair accuracy for angles of not greater than 45°. This rule is very simple, and may be thus given: "If the breadth of outcrop is measured at right angles to the strike, the true thickness will be one-twelfth of this breadth for every 5° of dip; or, in other words, if the angle of dip is divided by 60, the fraction obtained expresses the thickness of the strata in terms of the breadth of outcrop." Thus if the breadth of outcrop is 1,200 feet, and the dip is 15°, then the thickness of the strata will be $\frac{1}{4}$, or 300 feet. This is less than the true thickness by about 10 feet only. For angles exceeding 30°, the values calculated by Maclaren's Rule are slightly in excess of the true value. Taking, for example, an angle of dip of 35°, we find the thickness in the above case to be $\frac{35}{60}$ of 1,200, or 700 feet, the true value obtained by trigonometry being 688 feet.

We have next to consider some more difficult problems in connection with dip and strike which may occur in practice in geological surveying.

CHAPTER II.

True and Apparent Dip—Calculation of True Dip by Formula and by Graphic Construction—Dip and Strike Problems—Use of Dip Diagrams.

True and Apparent Dip.—In a perfectly level tract of country the outcrop of an inclined bed would be a perfectly straight line, the direction of which would be the *strike* of the bed. In practice the surface is seldom level, but it is, nevertheless, convenient to define the strike as the direction of the line of intersection of a horizontal plane with an inclined stratum; while *dip* is defined as the angle of inclination of a bed to the horizon. In ascertaining the angle of dip it is always necessary to observe accurately the direction in which the beds appear to slope, for it is obviously only in one direction that the *steepest* slope of the beds can be seen, viz., in the direction which is at right angles to the strike. This is the *true dip*; all other dip measurements will give only an apparent inclination varying in amount from the maximum value, or true dip, to zero, according to the angle which the exposed face of the cutting makes with the line of strike. It often happens, however, that the strike of a stratum is not accurately known at a given spot, so that some method is necessary by which the true dip can be calculated from any two observed dips in any direction whatever. When the direction of true dip is known, the strike is, of course, at right angles to this direction. It follows also that if inclined strata appear to be horizontal when viewed in a particular direction, this direction is the line of strike of the beds.

In most problems of this nature graphic methods are far more satisfactory than methods depending upon pure mathematics, as they only require accuracy of drawing to obtain results correct to the second place of decimals. There are some, however, who prefer mathematical calculations to the mechanical labour of plotting, so that both methods are given below, and their relative merits for practical purposes can be estimated by the reader.

Calculation of True Dip by Formula.—Let us first consider the case in which it is required to find the true dip from two apparent dips, denoted by α and β, in directions which are inclined to one another at an angle θ, which is, of course, the difference in the bearings of the apparent dips.

In the diagram (Fig. 9) $BDEC$ represents the horizontal plane, and $ADEC$ the plane of the stratum, of which, therefore, the strike is evidently the line DC. The supposed apparent dips are the angles ACB and ADB, represented by α and β respectively.

Then the angle DBC will be θ, the angle of inclination to one another of the planes of the apparent dips.

If BE is drawn perpendicular to DC, and AE joined, the angle AEB is the true dip, which we will denote by δ. Let the angle EBC be denoted by ϕ.

$$\text{Now } BE = BC \cos\phi = AB \cot\alpha \cos\phi.$$

$$\text{Also } BE = BD \cos(\theta - \phi) = AB \cot\beta \cos(\theta - \phi).$$

$$\text{Whence } \cot\alpha \cos\phi = \cot\beta \cos(\theta - \phi).$$

$$\text{That is } \tan\beta \cos\phi = \tan\alpha (\cos\theta \cos\phi + \sin\theta \sin\phi),$$

$$\text{or, } \cos\phi (\tan\beta - \tan\alpha \cos\theta) = \sin\phi \tan\alpha \sin\theta.$$

$$\text{Whence } \tan\phi = (\tan\beta \cot\alpha - \cos\theta) \operatorname{cosec}\theta \quad . \quad . \quad . \quad \text{(i).}$$

whence ϕ can be calculated.

$$\text{Also } \tan\delta = \frac{AB}{BE} = \frac{AB}{AB \cot\alpha \cos\phi} = \tan\alpha \sec\phi.$$

Thus we have the true dip δ expressed in terms of the apparent dips α and β.

We see also from the above formula that the apparent

dip varies with the angle ϕ. Now sec ϕ reaches its maximum value when ϕ is 90°, its value is then infinite, that is, the beds appear horizontal in a direction parallel to the strike. Also sec ϕ reaches its minimum value of unity when ϕ is 0°, that is, in a direction at right angles to the strike the apparent dip becomes the true dip.

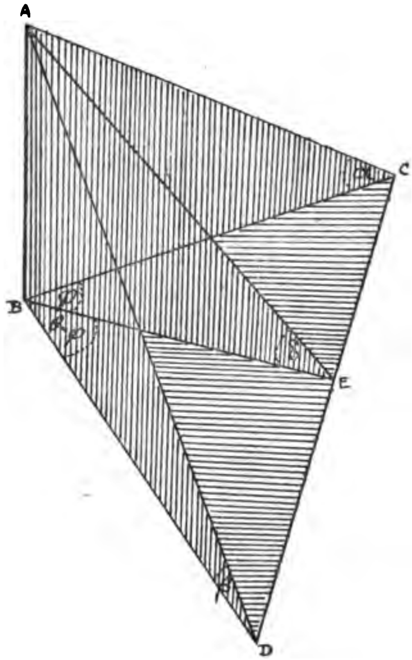

FIG. 9.

The above formula (i) is not adapted to logarithmic computation, and is, therefore, somewhat laborious in practical use, except in special cases, as, for instance, where two vertical faces of a quarry, on which the two apparent dips are taken, are at right angles to one another, in which case θ in the above formula becomes 90°, and tan ϕ reduces to tan β cot α.

In this case it can easily be shown that

$$\tan^2 \delta = \tan^2 \alpha + \tan^2 \beta.$$

Graphic solution of the above problem.—Graphic methods are more readily explained by actual examples. Let us, therefore, take one as follows :—

A stratum is seen to dip, on two exposed faces of a

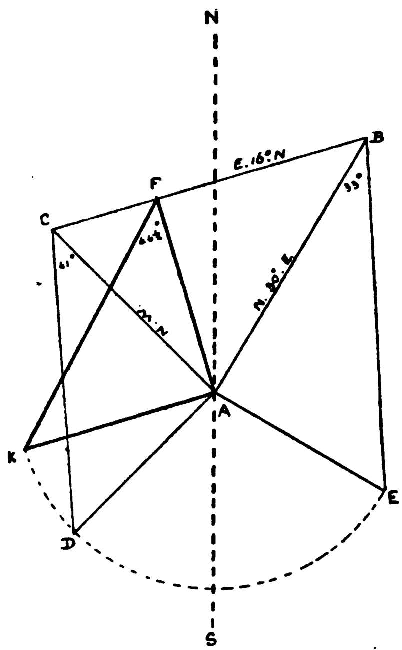

FIG. 10.

quarry, 41° in a N.W. direction, and 33° in a direction N. 30° E. Find its strike and the angle of true dip.

At the point *A* (Fig. 10) we proceed to plot the lines *AC* and *AB* in the observed directions of apparent dip, *AC* pointing N.W., and *AB* pointing N. 30° E. For plotting these figures a transparent circular protractor will be found very convenient. Now draw the perpendiculars *AD* and

AE respectively, of any convenient length, but equal to one another. We then make the angles *ACD* and *ABE* respectively equal to the two observed dips. This is most conveniently done by plotting the complements of the angles at *D* and *E* respectively.

Join *CB*. This line is the required line of strike, which the protractor at once shows to bear E. 16° N. Now to find the angle of dip.

Draw *AF* perpendicular to *BC*, and *AK* perpendicular to *AF*, making *AK* equal to *AD* or *AE*.

Join *KF*. The angle *AFK* is the angle of dip required, and is found by the protractor to be 44½°.

So that the stratum in question strikes E. 16° N., and has a true dip of 44½° in a direction N. 16° W.

Converse of the above problem.—Knowing the true dip it is often convenient to be able readily to ascertain the apparent dip in any given direction. This is especially necessary in drawing sections in certain directions across beds of which the strike and dip are known.

It has already been shown mathematically that the apparent dip may be obtained by multiplying the tangent of the angle of true dip by the cosine of the angle between the directions of apparant and true dip. Suppose, for example, that a seam dips 32° E., and we require to know what would be the apparent dip in a direction 37° S. of E., we multiply tan 32° by cos 37° to obtain the tangent of the angle required. Graphically, we draw *BC* in an E. direction (Fig. 11), and draw *AB* at right angles, of any convenient length. Make *ACB* equal to 32°, the angle of dip, and plot *BD* in the required direction, 37° S. of E., producing *BD* to meet *DC*, the perpendicular drawn at *C* to *BC*.

Join *AD*. The angle *ADB* is the angle required, and is measured by the protractor. In the construction of these figures, the larger the scale the more accurate will be the result. The figures in the text are, of necessity, drawn on too small a scale.

Dip and Strike Problems.—It is often convenient to lay down the line of strike upon the geological map itself, in order that a more correct idea may be formed of the lie of the beds than the winding lines of outcrop afford.

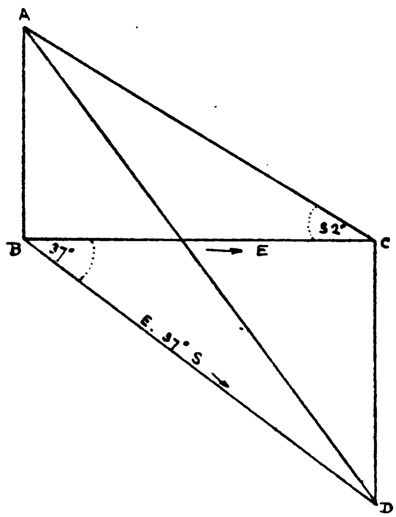

FIG. 11.

In this case the following method may be adopted with a close approximation to accuracy :—

In the diagram (Fig. 12) the winding line represents the line of outcrop of a stratum, which, at a point *A* in a quarry, affords two dip observations, one of which is 7° in a direction W. 3° N., and the other is 3° in a direction S. 5° E.

The straight lines *AL* and *AM* are drawn from *A*, by means of the protractor, in these directions respectively. Taking first the case in which the two observed dips are *concurrent*, *i.e.* both running either from or towards the point *A*, we now set off on *each* of the lines *AL* and *AM*,

a number of units corresponding to the number of degrees of dip observed along the *other* line. Thus, in the present case, we set off three units along *AL* and seven units along

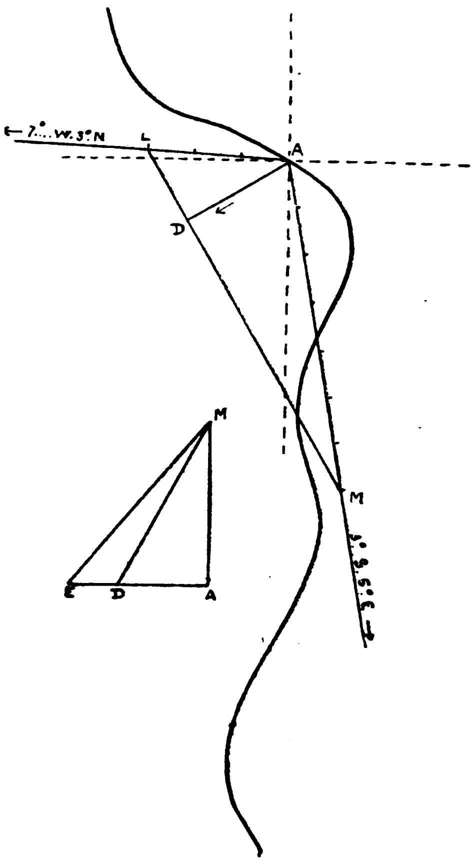

FIG. 12.

AM. If the angles are large and great accuracy is required, instead of the degrees of dip, the tangents of these angles should be taken.

Joining *ML*, we get the line of strike, and drawing *AD* perpendicular to *ML* we have *AD* the direction of true dip. To find the amount of dip we have only to construct a right angled triangle, as *AME*, having a base *AE* equal to *AL*, and the angle *AEM* equal to the observed dip 7° (exaggerated in the figure for the sake of clearness). This gives the perpendicular *AM*. We now lay oft *AD* along the base *AE*, and join *MD*. The angle *ADM* is the angle of true dip, and can be measured directly with the protractor.

If the two observed dips are not concurrent, we have only to *produce* one of the lines *AL* or *AM beyond* the point of convergence *A*, and proceed in the same manner as above, upon the concurrent lines thus formed.

Two examples are here given for practice, and as a test of the accuracy of the above methods.

Example 1.—Find the amount and direction ot the true dip of strata, which at a certain point are observed to dip 13° S.S.E., and 5° W.S.W.? [*Answer*, 14° S.]

Example 2.—Two apparent dips are observed at a point in a quarry, one being 3° 20′ N.W., the other 4° 20′ N.N.E. Find the amount and direction of the true dip. [*Answer*, 5° N.]

True Dip in the absence of any observed Dips.—It may often happen in practice either that a single dip observation alone is possible, or even that no observation at all can be made. Even in this case it is still possible to ascertain both the dip and strike of the beds, provided that the line of outcrop has been accurately laid down upon a map. For this purpose three points are selected *upon the line of outcrop*, which are conveniently situated for taking accurate levels. In the diagram (Fig. 13) the curved line represents the line of outcrop of a seam, and *A*, *B*, and *C* the selected points, *A* being the highest. The bearings of these points being taken from *A*, the lines *AB* and *AC* are laid down upon the map, and the distances *AB* and *AC* carefully

measured. We will assume in the present case that *AB* measures 200 yards, and that *A* is 75 feet above *B*.

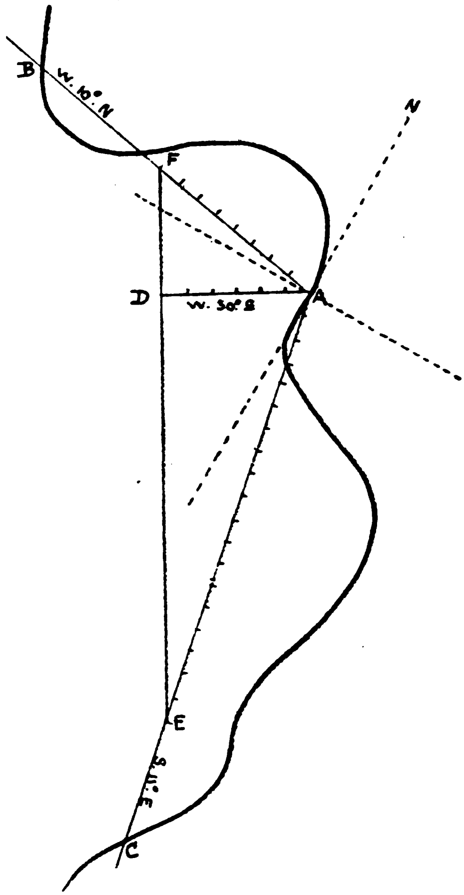

FIG. 13.

Similarly, let *AC* measure 400 yards, *A* being 63 feet above *C*.

The fall from A to B is 75 feet in 200 yards, which is 1 in 8. We mark off, therefore, 8 units along the line AB, giving the point F.

The fall from A to C is 63 feet in 400 yards, which is 1 in 19 nearly. We mark off, therefore, 19 units along the line AC, finishing at the point E.

Joining FE, we have the line of strike of the seam. From A draw AD perpendicular to FE. AD is the direction of true dip. Measure off the number of units contained in AD, in this case 6. The fall from A to D is therefore 1 in 6, and the true dip is $\tan^{-1} \frac{1}{6}$, or $9^\circ\ 27'$ in a direction W. 30° S. The direction is, of course, obtained directly from the figure by means of the protractor, but the angle must be taken from a table of natural tangents. In the absence of such a table, this angle can be at once read off from the proportionate incline by reference to the dip diagram to be presently described (see Fig. 19).

This method depends for its accuracy upon the care with which the line of outcrop has been mapped and the levels taken. It also assumes the absence of any sudden variations of dip within the area of observation. It is, however, quite sufficient for many practical purposes, and, indeed, in many cases is the only method which can be used at all.

To find the Strike and Dip of an Underground Seam by means of Bore-holes.—The case may often arise in practice in which it is required to fix the exact position of an underground seam which does not reach the surface in an accessible spot. Of course it will then be necessary to sink bore holes into the seam. The simplest case, which will now be considered, is that in which bore-holes are sunk at three of the angular points of a horizontal square. In Fig. 14, let us suppose that the bottom of each of these bore-holes reaches the seam at the points D, E, A respectively, so that $A\,E\,D$ represents the plane of the underground seam. It is obvious that the point F, in which DE produced meets the horizontal line $B\,C$ (shown here in

perspective), will be a point in the horizontal plane through *A*. Therefore *A F* must be the line of strike, since *A F* is horizontal.

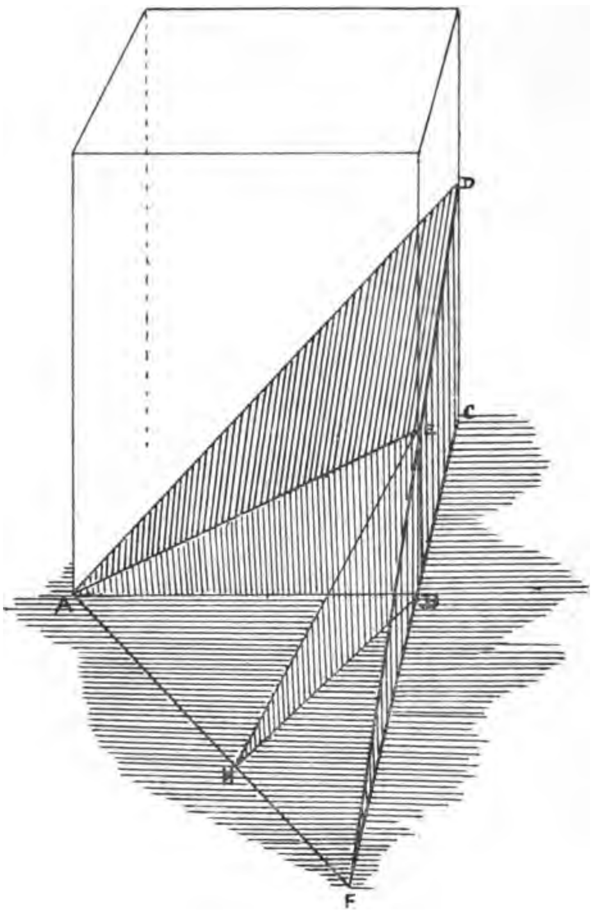

FIG. 14.

If now *B H* is drawn at right angles to *A F*, *E H* will represent the direction of greatest dip, and we have only to

solve the vertical triangle HED to find the value of the angle of dip BHE, which we will denote by δ. Let h be the side of the square, and a, b, c the depths of the bore-holes, a being the deepest, and b deeper than c.

Then evidently $BE=a-b$, and $CD=a-c$.

Also, since ABF is a right angle,

$$BH=h\sin BAF=BF\cos BAF$$

$$\text{or } \frac{BF}{h}=\tan BAF.$$

$$\text{But } BF : BE :: FC : CD,$$

$$\text{that is } BF : a-b :: BF+h : a-c,$$

$$\text{whence } BF=\frac{h\,(a-b)}{b-c}$$

$$\text{so that } \tan BAF=\frac{a-b}{b-c}.$$

$$\text{Now } HB=h\sin BAF=\frac{h\tan BAF}{\sqrt{1+\tan^2 BAF}}=\frac{h\,(a-b)}{\sqrt{(b-c)^2+(a-b)^2}}$$

And $\tan\delta=\frac{BE}{HB}$, which, by substitution, becomes

$$\frac{\sqrt{(b-c)^2+(a-b)^2}}{h}.$$

Thus we have the angle of dips in terms of the depths of the bore-holes and the side of the horizontal square. This formula becomes more complicated if the bore-holes are not made at the angular points of the square, but in practice it is nearly always possible to secure this condition. If not, the following graphic method will apply to any case whatever.

Graphic Construction for the above Problem.—Let the position of the three bore-holes be accurately laid down upon a plan. In the accompanying diagram (Fig. 15) the points A, B, C represent the three bore-holes, which can occupy any position whatever so long as they are not in a straight line. Let A be the position of the deepest, and

C the position of the highest point of the seam. At *C* draw a perpendicular *CD* equal to the difference in depth of *A* and *C*, and at *B* draw a perpendicular *BE* equal to the difference in depth of *A* and *B*. Join *DE*, and produce it to meet *BC* produced in *F*.

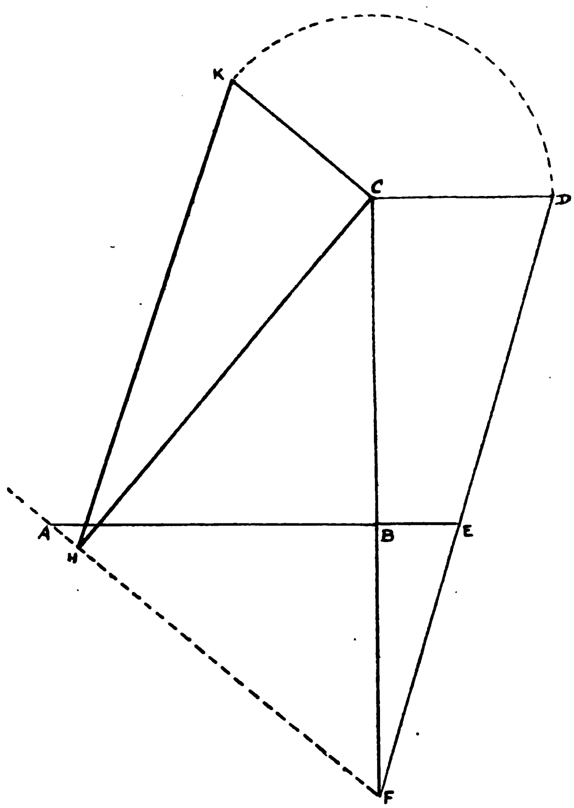

FIG. 15.

Join *AF*. Then *AF* is the line of strike, and its direction may be read off directly from the figure with a protractor. It is obvious that *F* is on a level with *A*, since

DE represents the inclination of the seam between *C* and *B*.

Now, to find the dip, we draw *CH* perpendicular to *AF*, and *CK* perpendicular to *CH*, making *CK* equal to *CD*. Join *KH*, then *CHK*, the angle of dip, may be measured directly with the protractor.

The following example may be drawn for practice: Three bore-holes are made into an underground seam as follows:—In Fig. 15 $AC = 150$ yards, $BC = 112$ yards, and

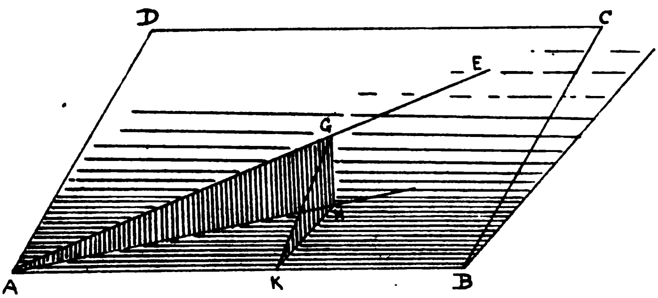

FIG. 16.

$AB = 100$ yards. The bearing of *AC* is S. 7° 30′ *E*. The depths of the borings are 83 yards at *A*, 51 yards at *B*, and 10 yards at *C*. Find the true dip and strike of the seam. [*Answer*, The seam strikes E. 8° N., and dips 25° 58′.]

Dip of an Underground Seam in which a Heading has been driven.—When a seam has been opened by a heading driven along it, the strike is readily found if it is remembered that the strike is the intersection with the seam of a horizontal plane, that is to say, the bearing of a horizontal line connecting two vertical props set up in the axis of the tunnel. In Fig. 16 let *ABCD* be the plane of a seam, and *AHB* the horizontal plane. Then *AB* is the line of strike. From any point *G* in the seam let fall *GH* perpendicular to the horizontal plane, and join *AH*. Draw *HK*

perpendicular to AB and join GK. Then GKH is the dip of the seam.

Now the bearings of AH and AB are known, therefore the angle HAK, the difference of these bearings, is known. Denote this difference by e. The angle GAH, the dip of the heading, is also known. Let this be denoted by b. Then $GH = AG \sin b$, and $HK = AH \sin e = AG \cos b \sin e$. Therefore $\tan GKH = \frac{GH}{HK} = \frac{AG \sin b}{AG \cos b \sin e} = \frac{\tan b}{\sin e}$, whence the angle of dip is readily calculated by a table of logarithms.

Example 1.—What is the dip of a seam which strikes E. 37° 30′ S., if a diagonal heading driven in it dips 4° and courses due E.? [*Answer*, 6° 33′ 10″.]

Example 2.—Find the dip of a seam which strikes E. 8° 30′ S., in which a diagonal heading dips 5° and courses E. 30° N. [*Answer*, 8°.]

Dip Diagrams.—When the dip of a seam has been determined, it can easily be calculated at what depth below the surface the seam will be reached by a shaft sunk at any point, or what will be the length of an adit driven in a hillside to reach the seam.

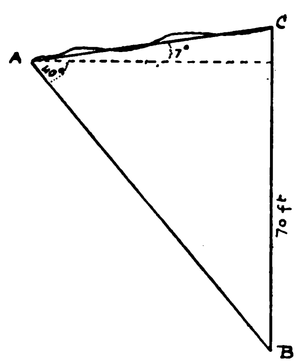

FIG. 17.

Mathematically these problems are solved as in Figs. 17, 18. Suppose a seam, represented in Fig. 17 by AB, has to be pierced by a shaft at a depth of 70 feet below the surface, and we require to know at what distance from the outcrop at A, measured along the surface of the ground, the shaft must be placed. The dip of the seam being

known, and the slope of the ground likewise, the angle BAC is the sum of these angles, and the angle at B is also known, being the complement of the dip angle.

Therefore we have $AC = \frac{BC \sin ABC}{\sin BAC}$, or with the values assumed in Fig. 17, $AC = \frac{70 \times \sin 47^\circ}{\sin 50^\circ}$, which can easily be calculated from a table of natural sines.

Similarly, the length of an adit at a point in a hillside, sloping at an angle, to reach a seam dipping either towards or away from the hill slope, is found by drawing the diagram, as in Fig. 18, where the slope of the hill is taken as 27°,

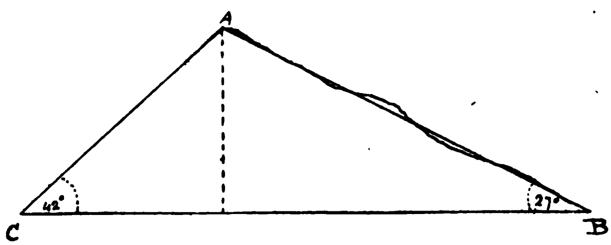

FIG. 18.

and the dip of the seam 42° in the opposite direction. From the figure it is seen that the required length $BC = \frac{AB \times \sin 63^\circ}{\sin 48^\circ}$.

These and other problems of a similar nature can be at once solved without the aid of trigonometry by means of the diagram shown in Fig. 19. To construct such a diagram, which should be on a larger scale than the figure shown, it is only necessary to take a piece of paper which has been ruled into squares. A very convenient paper for the purpose can be obtained of physical instrument manufacturers, ready ruled into centimetre squares, subdivided into millimetres. If each centimetre be taken to represent

one foot, we can thus measure tenths of a foot. In Fig 19 distances of five feet only are shown, the diagram covering 200 feet horizontally and 100 feet vertically. The scale can of course be varied to suit any requirements, and can be increased indefinitely in size.

The next thing is to mark off from the top left-hand corner, with a protractor, angles from 0° to 90°. For the sake of clearness intervals of 5° only are shown in the diagram.

The use of the diagram will be at once evident from the following examples. Suppose a seam or lode dips at an angle of 65°, and it is required to sink a shaft to reach it at a depth of 55 feet below the surface. We follow the diagonal line of 65° downwards on the diagram until it crosses the horizontal line marked 55 on the vertical scale, which it does at the point marked *A* on the diagram. Following the vertical line upwards from *A* we find that the shaft must be sunk at a distance of 25 feet measured horizontally from the outcrop. If the surface of the ground rises or falls from the outcrop, the required depth of 55 feet will be reached higher or lower along the line of 65° as the case may be. Thus, suppose the ground falls from the outcrop at an angle of 30°, and we require to cut the seam at a depth of 55 feet as before, we must in this case follow both the diagonal lines of 65° and 30° downwards, until the *vertical distance between them* is just 55 feet. This point is found at *K*, *EK* being 55 feet vertically, and the distance between the outcrop and the point *E* will be the distance required. If the ground rises instead of falling, it will be better to extend the diagram upwards above the horizontal line through the outcrop until the required angle of the slope of the ground is reached. The distance can then be measured off as before.

Let us take one more example. A seam dips at an angle of 40°, and we require to know the length of an adit driven in a hill-side, of which the slope is 25°, to reach the

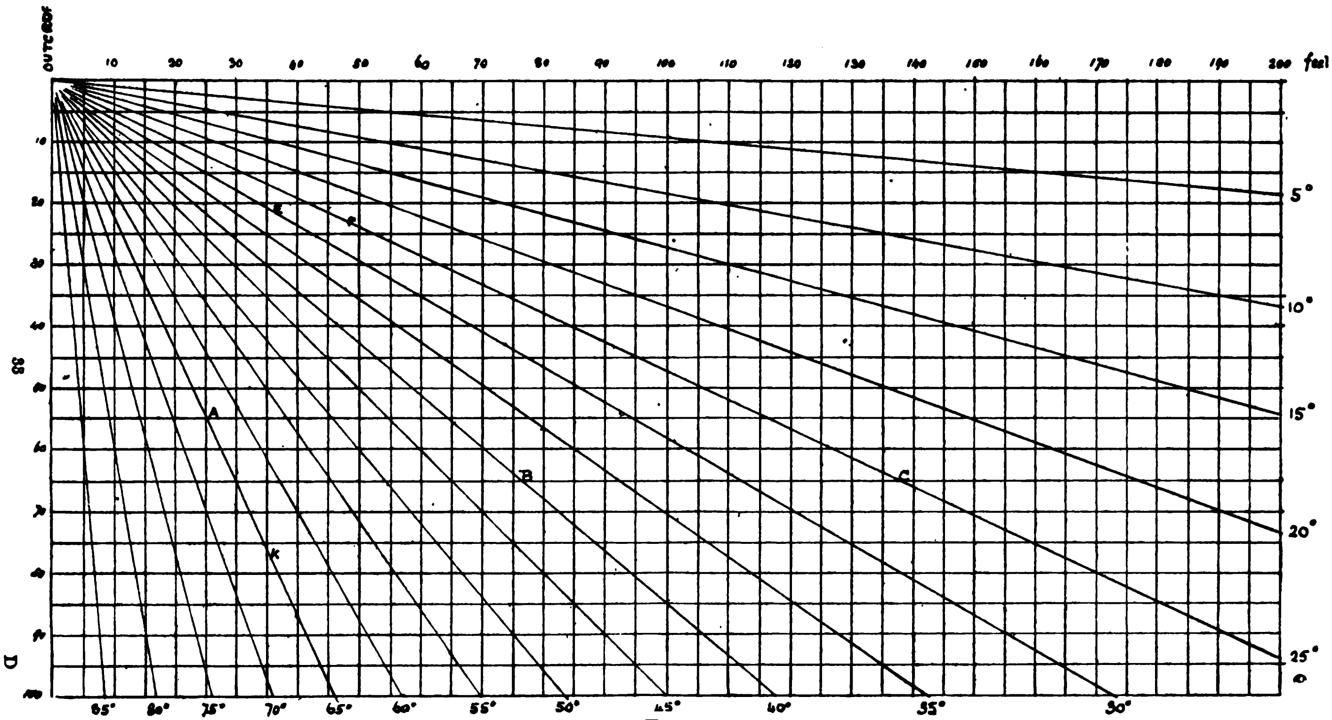
OUTCROP
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 feet
5° 10° 15° 20° 25°
85° 80° 75° 70° 65° 60° 55° 50° 45° 40° 35° 30°
A
B
C
E
F
K
D

FIG. 19.

seam at a vertical depth of 65 feet. We now follow the angle of 40° downwards until it intersects the horizontal line of 65, figured *B* on the diagram. Follow the horizontal line from B until it intersects the angle 25°, which it does at the point *C*. Then the distance *BC* will be the required length of the adit, and measures nearly 63 feet on the scale.

If the seam dips away from the slope of the hill, the distance required will be *BC* added to twice the distance from *B* to the vertical line at the outcrop, that is to say, in the present case it will be 63 together with twice 77 feet, or 217 feet.

Hitherto we have considered the case of the dip and strike of strata in undisturbed areas. Such problems are naturally more difficult in disturbed and dislocated districts, to which our attention will be next directed.

CHAPTER III.

Irregularities in Stratified Rocks—Thinning out of Beds—Unconformity and Overlap—Curved Strata—Faults—Normal Faults.

Irregularities in Stratified Rocks.—Hitherto we have considered strata as geometrical planes occupying certain definite positions in the earth's crust. In those localities in which the rocks have not been much disturbed, and when small areas only are considered, this assumption is sufficiently true for practical purposes. Many strata have been simply tilted during upheaval, without having undergone any violent contortions. In the Western States of N. America thousands of square miles of stratified rocks are still almost perfectly horizontal, although upheaved in some cases as much as 10,000 feet above sea-level. Even where strata have been thrown into the most complicated folds, it is often impossible in a small area to recognise more than a simple inclination of the beds, and the rules just laid down will be found as applicable, within the limits of a single mine or quarry, as if no such complications existed. On the other hand, the foldings may be of so sudden a nature as to produce a change of dip within the distance of even a few feet, to the confusion of calculations based upon an insufficient geological survey. It is obviously advisable, therefore, to explore the strata over as wide an area as possible, in order to obtain a correct view of the true structure of the underlying rocks. The continuity of even the most persistent beds must sooner or later be interrupted, possibly with disastrous results to the prosperity of important industrial undertakings. It is of

the first importance, therefore, to learn to recognise the signs of any approaching irregularity, and to estimate its effect upon the future development of the strata. For this purpose it must be remembered that the present condition of the rocks of the earth's crust is the result of several causes, depending partly upon the physical conditions under which they were deposited; partly upon the disturbances and dislocations which they have undergone and partly upon the effects of denudation.

Thinning out of beds.—Wherever a valuable seam, whether of building stone, coal, or any other rock is known to occur, its probable area becomes a question of the first importance. Is it likely to be an extensive deposit, or one which will rapidly thin out and disappear? Actual measurements of the thickness of the deposit in different directions may be possible, always remembering the caution previously given against attempting to estimate thickness by the width of outcrop alone. Where outcrops diminish in width, however, without any variation in dip or unusual surface irregularity of the ground, a thinning of the strata may be safely assumed.

But it is sometimes necessary to form an opinion as to the lateral extent of a bed in the absence of any actual measurements of thickness. For this purpose we go back in imagination to the period of deposition of the strata in question, remembering that while the finer sediment is carried out to sea, coarser materials are deposited near the shore, and that organically formed limestones are usually formed beyond the limits of land detritus. It follows from this that there is a definite relation between the lateral extent and lithological composition of strata. Coarse beds of conglomerate or sandstone, although often thick locally, thin out much more rapidly than finer deposits of shale or limestone. Organically formed rocks often persist over large areas. Beds of shale in the coal measures, such as the "Table batt" of S. Staffordshire,

often cover an area of several square miles, while in the same coal-field the bed of sandstone known as the "New Mine Rock" thins out from 78 feet to 9 feet in the course of a few yards. Organically formed rocks are generally far more persistent than those of mechanical origin, a fact well illustrated by the phosphate deposits both of Europe and America, which often in thin seams occupy the same geological horizon over immense areas. Any variation, therefore, in lithological character, and especially a marked change in the size of the particles, may serve as an indication of the lateral extension of the bed, the coarser the grain the more local being its extent.

Thus the miner and the quarryman are influenced to no small extent by the physical geography of past epochs, not only in the choice of the exact locality in which new mines or quarries should be opened, but also as regards the character and quality of the rocks which they are seeking.

Unconformity and Overlap.—Intimately connected with the thinning out of beds is the extension of the area of deposit of higher strata beyond the limits of the beds lying immediately below, an occurrence which is called an *overlap*. The practical importance of an overlap is at once evident from Fig. 20, in which the bed *B* is seen to extend

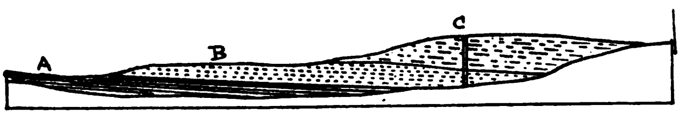

FIG. 20.

beyond the limits of *A*. A person unacquainted with the phenomena of overlap might reasonably suppose that a shaft sunk at *C* would reach the bed *A* lying beneath it, a conclusion leading obviously to failure.

The form of the old land surface, upon which sedimentary strata were originally deposited, not only affects the direction in which these strata may be expected to thin out and disappear, but may also cause a sudden and

unexpected break in continuity which may be difficult, if not impossible, to foresee. Such a break in the succession of strata, called by geologists an *unconformity*, denotes an interval of time during which the area in question stood high and dry above water. When at last sedimentation was resumed, the deposits were laid down upon a disturbed and eroded foundation consisting of rockers of far greater antiquity than the series overlying them. Such a condition of things is represented both in plan and section by the diagram (Fig. 21) in which the older strata are seen to have been thrown into anticlinal and synclinal curves, and to have suffered great denudation before the nearly horizontal strata were deposited upon them. Subsequent denudation has again exposed one of the synclinal basins in the older rocks, otherwise their existence beneath the horizontal strata might never be suspected.

A notable instance of such a break in the succession of strata is the well known failure to reach the Lower Greensand by boring through the chalk at Kentish Town, owing to an intervening ridge of Palæozoic rock upon which the Upper Cretaceous strata were unconformably laid down.

There is no better illustration of the practical importance of this point than the many futile attempts which have been made to reach the coal-measures by boring through the Mesozoic strata of England. Mr. Jukes-Browne gives an instructive example of the probability of finding coal beneath the Triassic sandstones which border the Bristol coal-field. The diagram (Fig. 21) may be taken as roughly representing the Bristol coal-field, lying in the synclinal basin on the left, and the Cotteswold Hills forming the higher ground on the right. A boring made through the Cotteswold Hills could only pierce the anticlinal, which might be expected to abut against the Bristol synclinal. To find coal the next synclinal, on the extreme right of the diagram, must be pierced. Indeed, such a coalfield has, in fact, been reached at Burford, in Oxfordshire, at a

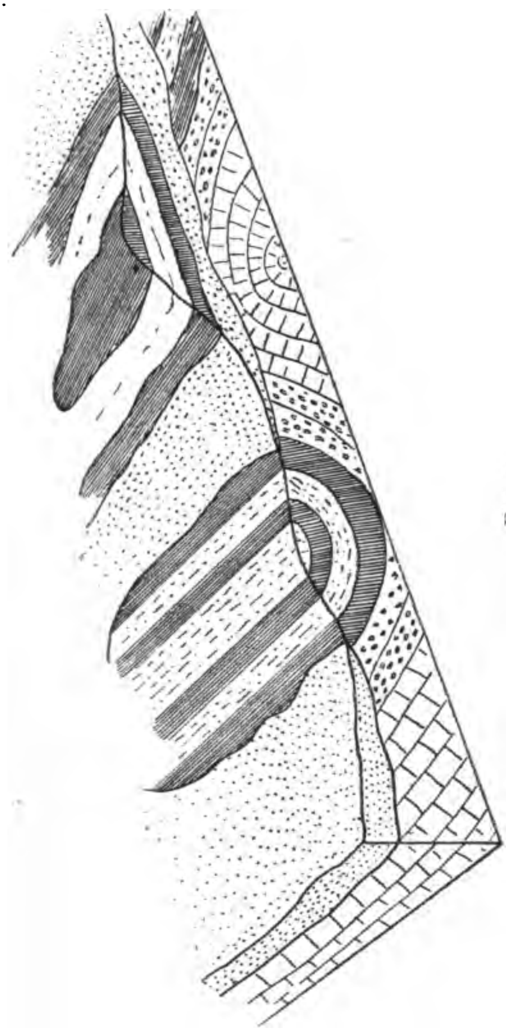

FIG. 21.

depth of 1000 feet below the surface. The existence of such coalfields, covered unconformably by newer rocks,

will become a question of increasing importance as we approach nearer to the limit of our present supplies.

Whenever, therefore, it is proposed to reach a deposit by boring through overlying beds, it is necessary to ascertain whether there is an unconformity between the two formations; and, if this should be the case, evidence must be obtained as to the disturbances and denudation which the older rocks had undergone before the newer strata were deposited. An instructive example of the importance of recognising the true meaning of an unconformable junction is seen in the situation of the gold-bearing deposits at the base of the coal measures in New South Wales. It has been suggested that the position of this deposit below the Carboniferous conglomerate leads to the inference that these conglomerates themselves may be auriferous. But, as Mr. Davies has pointed out,[1] the fact that these beds lie uncomformably upon Silurian strata, the gold being found at the junction, proves conclusively that this gold was in fact derived from the abrasion of the Silurian rocks, from which the Carboniferous conglomerates were mainly derived. It would, therefore, be futile to search for the source of this gold in the overlying Carboniferous deposits. This case emphasises the important fact, which the practical man should always bear in mind, that the lower beds of newer strata, lying uncomformably upon older beds, are mainly conglomerates derived from the older beds themselves.

Curvatures.—From the foregoing remarks it will be evident that the folds into which strata have been thrown play an important part in economic geology. One result of this folding has been the preservation in synclinal hollows of strata which have long since been denuded from the anticlinal ridges, many of our British coalfields, as seen above, owing their existence to this cause. To the miner and the quarryman the nature of these foldings

[1] *Metalliferous Minerals and Mining*, p. 70.

is of great practical importance, for not only are useful beds often repeated by this means many times within a small area, but also are often brought up again to accessible depths just at the time when they might otherwise have to be abandoned. A noteworthy instance of this occurs in the case of the gold-bearing quartz reefs, called saddle reefs, of Bendigo, where a series of sharp folds causes a repetition of the reefs successively downwards, and some of the deepest gold mines in the world exist in consequence.

How then is the existence of such flexures to be recognised? To answer this question let us study carefully a simple case shown in Fig. 22, reproduced from a geological map of N. Staffordshire. The strike of the different strata in this case, instead of running in a straight line, forms a closed curve. Now it is evident from what has already been said as to the relations of dip and strike, that wherever the strike deviates from a straight line, the strata must be bent out of their former plane. If we attempt to draw a section across this map in any direction, it will be found that the only possible explanation of the repetition of outcrops is to be found in either an anticlinal or synclinal fold. In the former case the older beds would occupy the centre, in the latter case the newer would be in this position. In other words, the strata would dip outwards in the case of an anticlinal, and inwards in the case of a synclinal.

Now it is not conceivable that a single fold of any magnitude would exist alone. If, therefore, as in the case of the Bristol coal-field, a single synclinal appears at the surface, it may be reasonably assumed that a system of folds exists underground in the concealed areas adjoining, as shown in Fig. 21. Such folds, however, sooner or later, die away altogether. The axis of a fold, which may be compared to the ridge of a roof (inverted in the case of a synclinal), may be of any length. When this axis is reduced to zero, the fold becomes either a *dome* or *basin*,

having a quaquaversal dip and a more or less oval strike, as in the diagram Fig. 22. The inclination of the axis is called the *pitch* of the fold, a long gentle pitch giving rise to an elongated trough or ridge, a short steep pitch

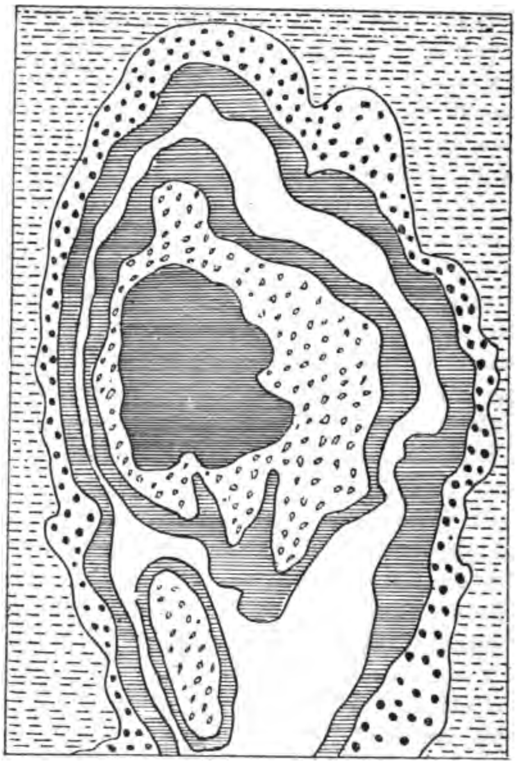

FIG. 22.

forming basins or domes. The position of the plane of the axis also gives rise to a great variety in the forms of the curves, which may vary from simple symmetrical undulations to a complete inversion of the beds.

Faults.—When strata are unable to accommodate them-

selves to the stresses exerted upon them by simple bending, fractures are the result; and when such fractures are accompanied by dislocation, that is to say, by more or less displacement of the strata, a *fault* is produced. The plane of fracture is seldom vertical, and its position with reference to the vertical plane is called the *hade* of the fault. There is this difference between the hade of a fault and the dip of a bed, that the former is the angle between the fault plane and the vertical, while the latter is always measured from the horizontal plane. The term *fault dip* is also used, and denotes the inclination of the fault plane to the horizontal.

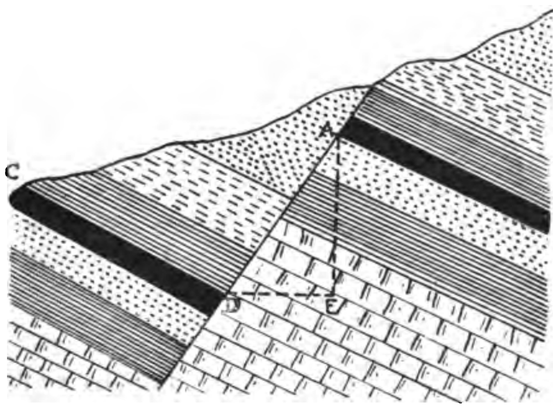

FIG. 23.

Thus the angle of fault dip must be the complement of the hade. A vertical fault plane would have no hade, but its dip would be 90°.

Since there is a displacement of strata on either side of a fault, the beds on one side of the fault plane lie at a higher level than those on the other side. The two sides are, therefore, called respectively the *upthrow side* and *downthrow side* of the fault, while the walls of the fault plane are distinguished as *hanging wall* and *foot wall*, the former being on that side on which the beds project over

those on the other side. The vertical distance between the ends of a displaced bed is called the *throw*, the corresponding horizontal distance being known as the *heave*, although often called by miners the *width of the fault.* The distance, measured at right angles to the bedding planes, between the displaced portions of a bed is sometimes called the *stratigraphic throw*. These terms will be at once understood by reference to Fig. 23, where *AB* is the upthrow side, *CD* the downthrow side, and the left hand wall of the fault plane is the hanging wall. In this case, also, *AE* is the throw and *DE* the heave of the fault; while *AD*, being by accident at right angles to the bedding planes, measures the amount of stratigraphic throw. It is evident from the diagram that the heave increases with the hade, and that if the fault is vertical, however great the throw there can be no heave at all.

In the case of mineral veins, which are usually highly inclined, the amount of lateral shift produced by the fault is alone considered in practice, the vein miner speaking of *left-hand* or *right-hand heaves* instead of the upthrows and downthrows of the quarryman or bed miner. The throw of a fault is never constant along the whole fault plane, but varies both laterally and vertically. In deep mines it is generally found that the throw diminishes with the distance from the surface. The lateral variation in throw may be easily illustrated by cutting a slit in a piece of india-rubber. If one side of the slit is either pressed downwards or puckered upwards it will be seen that the throw of a fault may continually change in amount and direction until at length the fault dies away altogether. In Fig. 24 this variation is clearly shown. Any variation in the dip of the strata must also influence the amount of throw of a fault cutting the strata in any direction not parallel to the strike. When a fault at length dies out, its termination is often marked by splitting up into a series of minor faults, which in their turn gradually die away.

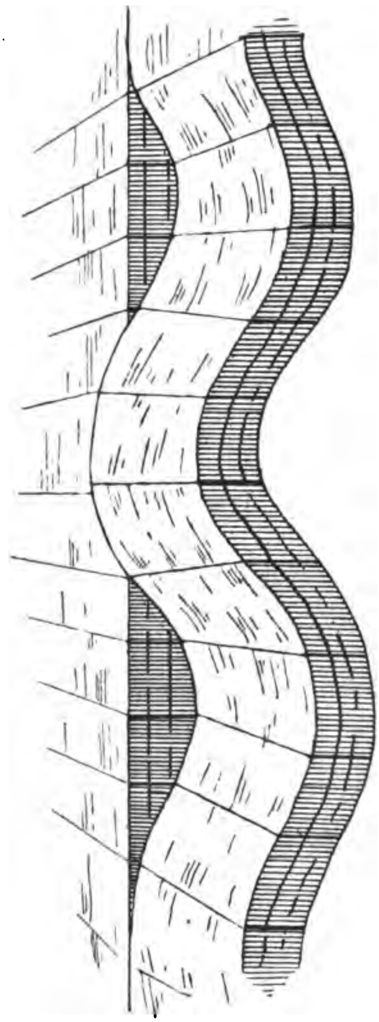

FIG. 24.

The condition of the fault plane depends partly upon the nature of the rocks, and partly upon the nature of the frac-

ture. In soft rocks, such as shales, sandstones or thin limestones, the fault plane is often a clean cut fissure, fitting closely; but in harder strata the fissures are wide and irregular, and often filled with a mass of broken debris, known as *fault-breccia*, or *fault-rock*. The fracture is sometimes more or less jagged or undulating, in which case hollow spaces are caused by the sliding of the uneven surfaces upon one another. The direction of motion of the surfaces is sometimes preserved in grooves and striations on the walls of the fault, resulting often in a more or less polished surface known as *Slickensides*.

Large faults are often accompanied by a number of smaller ones, often more or less parallel to the main fissure, producing a series of *step faults*. In other cases two fault planes, hading in opposite directions, produce by their intersection a wedge-shaped piece known as a *trough* fault.

Normal Faults.—In areas which have not suffered an abnormal amount of disturbance it is almost universally the rule that the hade of the fault is towards the downthrow side. Such faults are called *normal* faults, and, since the displaced beds occupy a greater space than before, they may be looked upon as a result of tension. The probable explanation of the rule above given is to be found in the fact that the smaller base of support would yield more readily to downward forces, and this would naturally result in a slipping down of that side towards which the fault plane is inclined. Of course the same result would be produced by an upthrust of the lower or foot wall side of the fault.

Two distinct kinds of normal faults exist according to the direction taken by the strike of the fault plane with reference to the strike of the strata which it traverses. Thus we have *strike* faults, running more or less parallel to the strike of the strata, and *transverse* or *dip* faults, cutting across the beds at an angle with the strike. The effect of these two kinds of displacements on the strata

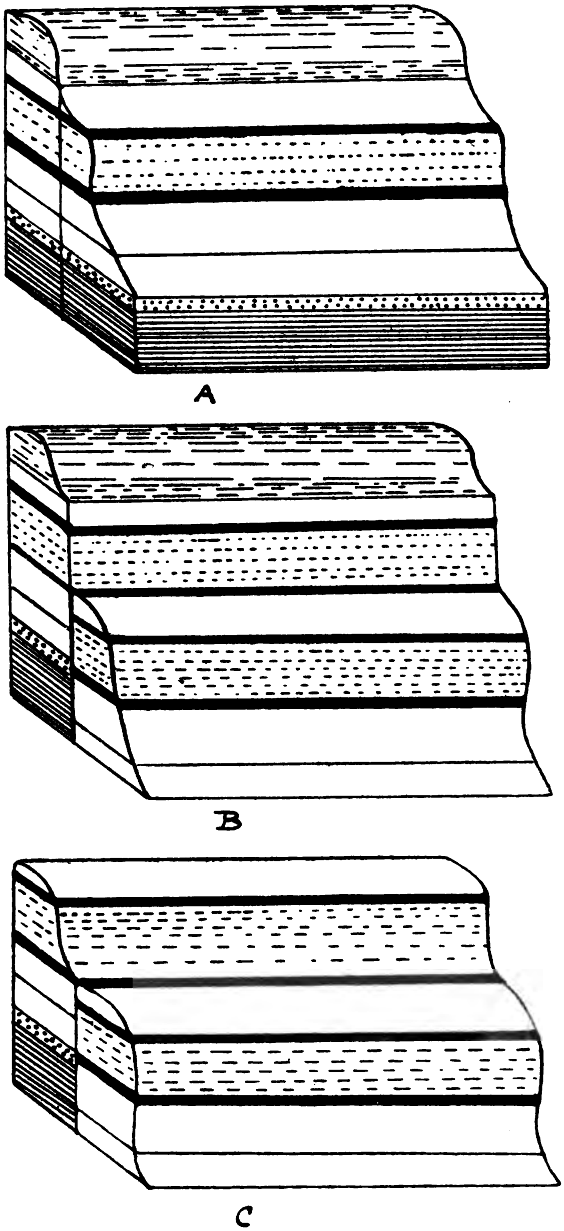

Fig. 25.

which they traverse is best explained by models, of which excellent examples, made by the late Mr. Sopwith, may be studied in the Museum of Practical Geology. The three diagrams shown in Fig. 25 are intended to illustrate the three stages of displacement of horizontal strata by a strike fault. In *A*, the strata are shown in position before displacement. In *B*, motion has taken place downwards, showing a fault scarp. In *C*, the fault scarp has been more or less worn down by denudation. The final effect, therefore, of such a fault is to repeat the outcrops, giving a deceptive appearance as to the number of strata exposed. It is important to notice, also, that strike faults produce no lateral displacement of the outcrop. If, however, the fault hades in

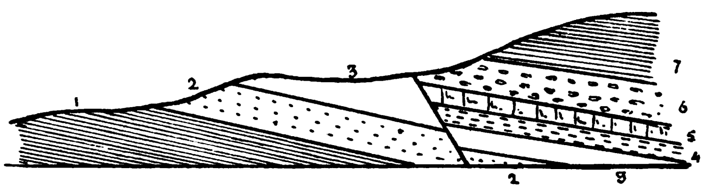

FIG. 26.

the same direction as the dip of the strata, instead of a repetition of the outcrops, some of the beds will be hidden behind the fault, and so prevented from appearing at the surface at all. This is illustrated in the section, Fig. 26, where a surface survey would show only the beds, 1, 2, 3, 6, 7, and no indication is seen at the surface of beds 4, 5 which are cut out by the fault. A glance at Fig. 27 will show how complicated the outcrops may become when traversed by a series of strike faults. If the black bands be supposed to represent seams of coal, of which two only exist in reality, their repetition by the three parallel faults may lead to the conclusion that there are seven such seams cropping out at the surface, a delusion which is at once dispelled by an examination of a sectional view of the model.

In the case of dip faults, the continuity of the outcrop is

invariably interrupted, the *downthrow side being displaced in the opposite direction to the dip of the beds*, the amount of displacement increasing with the throw of the fault, and diminishing as the angle of dip of the beds increases. This important rule is sometimes given thus: the downthrow side of the outcrop is shifted towards the rise. The only

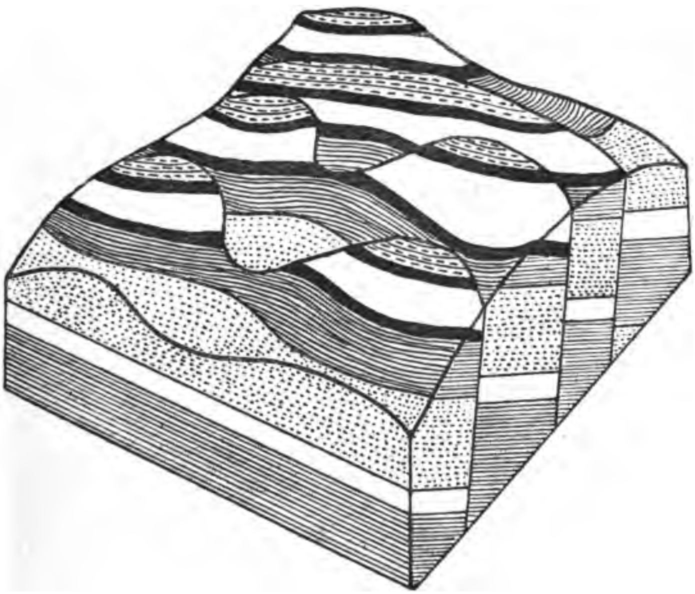

FIG. 27.

case in which the rule would fail is when the ground slopes with the dip and at a greater angle, when the displacement of the outcrop would be towards the dip. In Fig. 28 the reason for the above rule is made clear. The top model shows a series of strata in position. In the middle figure, displacement has taken place along the plane of a dip fault, the fault scarp showing the amount and direction of the movement. The lower figure shows the fault scarp

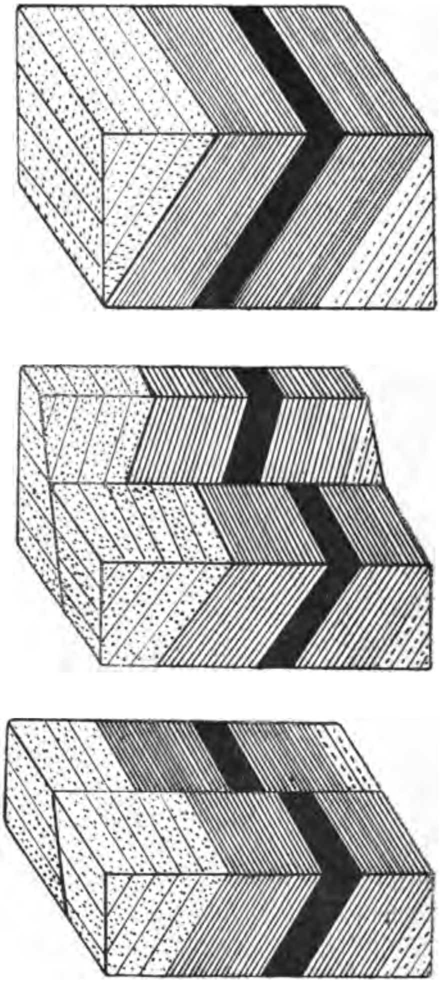

FIG. 28.

denuded away, and the resulting displacement of the outcrop on the downthrow side in the opposite direction to

the dip of the beds. It is evident that this result must follow from the fact that the surface of the ground cuts the upthrow side at a *lower stratigraphic level* than the downthrow side.

In the case of folded strata the displacement of the outcrop becomes more complicated. In Fig. 29, the upper block represents an anticlinal curve traversed by a trans-

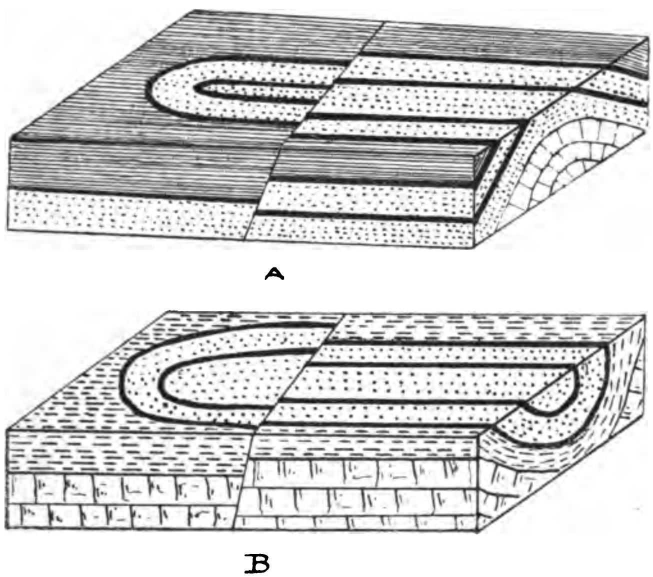

FIG. 29.

verse fault. The downthrow side of the fault is here distinguished by the diminution of the distance between the two limbs of the anticlinal, which, as before, is easily intelligible if it is remembered that the upthrow side is on a lower stratigraphic level, and that the limbs of the anticline diverge downwards. In the case of a syncline, shown in the lower block, the reverse is the case. The limbs of the syncline converge downwards, so that the upthrow

side of the fault is marked by a narrowing of the outcrop widths.

Knowing these rules, it is generally possible to tell from the nature of the displacement of outcrop which is the downthrow side of a fault, and consequently the direction of the hade. A great deal still remains, however, to be said on the important subject of ults, to which another chapter must be devoted.

CHAPTER IV.

Reversed Faults—Surface Indications of Faults—Practical Influence of Faults in Mining and Quarrying—Calculation of Throw—Search for Dislocated Veins: Zimmermann's Rule.

Reversed Faults.—These faults differ from the normal faults just described in having a hade towards the upthrow side. Being a result of compression instead of tension, the strata on breaking have been pushed over one another, as in Fig. 30. In this case a perpendicular from the upthrow side would pierce the displaced bed on the downthrow side, which could never happen in the case of a fault of the normal type. These faults usually occur only in highly disturbed rocks, as a result of excessive folding from lateral pressure. They always hade at greater angles than those of the normal type, the fault plane frequently being nearly horizontal. Being generally parallel to the strike, reversed faults produce a repetition of outcrop if not of too large a displacement; but it often happens that beds so widely separated stratigraphically are brought into juxtaposition, so that no such repetition is visible.

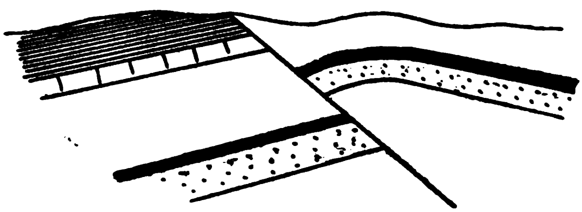

FIG. 30.—Reversed Fault.

Surface Indications of Faults.—Except in the compara-

tively rare case in which a fault is visible in a cliff or on the exposed face of a quarry, there are, to the untrained eye, few or no surface indications of the displacement which has taken place. As a rule, the greater the fault the less evident will it be from any surface features; for the great crushing which strata have undergone in the vicinity of a large fault, as well as the consequent bringing together of rocks of varying degrees of resistance to the forces of denudation have usually resulted in the accumulation of a mass of débris which effectually conceals the line of fracture. Hollows, also, often characterise the line of weakness along which the fault runs, and in these hollows superficial accumulations generally occur. In exceptionally dry localities, however, as in some of the Western States of America, where atmospheric denudation has been slow, the upthrow side of faults often forms a conspicuous cliff or fault scarp. It is generally necessary, therefore, to fall back upon indirect evidence of the existence of a fault, of which the position and even the throw can often be as accurately worked out as if the displacement were actually visible.

We will now consider, in some detail, the nature of this evidence, but it does not of course follow that a fault will necessarily reveal its existence by all of these indications at the same time.

(*a*) A line of springs, not coinciding with a boundary line between permeable and impermeable strata, may be the result of a fault, as in Fig. 31, where the permeable bed *AB*, interrupted by a fault, throws out springs, as at *S*, along the strike of the fault plane.

(*b*) Although the fault scarp in most cases has been worn down by the excessive denudation of the upthrow side, yet it sometimes happens that *traces* of this fault scarp exist in an abrupt change in the form of the ground, not coinciding with a boundary line between hard and soft strata. This is still more likely to be the case if the upthrow side consists of harder strata than the downthrow side.

(*c*) In the majority of cases the strata in the neighbourhood of a fault are sharply bent, upwards on the downthrow side and downwards on the upthrow side of the fault. If, therefore, a rapid change is noticed in the dip of strata, *always on approaching a certain line*, the existence of a fault may be suspected and confirmation sought for by additional evidence.

(*d*) Certain rocks suddenly lose all trace of bedding planes, becoming broken and traversed by parallel cracks when approaching the plane of a fault, a phenomenon known as "ruttles" in sandstone quarries.

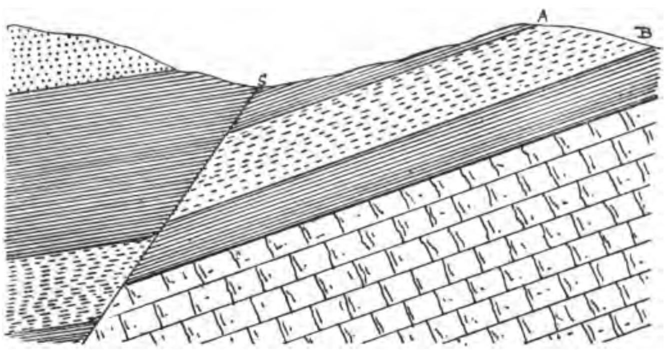

FIG. 31.—Spring Caused by a Fault.

(*e*) In the process of mapping outcrops it will often be noticed that a *sudden* divergence of strike occurs on either side of a given line. In technical language, one set of beds strikes against the other. Thus, in Fig. 32, the left hand portion shows a series of outcrops met with in the bed of a stream, and changing *abruptly* in direction on approaching a certain line. On completing the map, as in the right hand portion of the diagram, it is found that no possible bending or curving of the strata could account for such a change. Neither is there any evidence of an unconformity. The only possible explanation, therefore, is

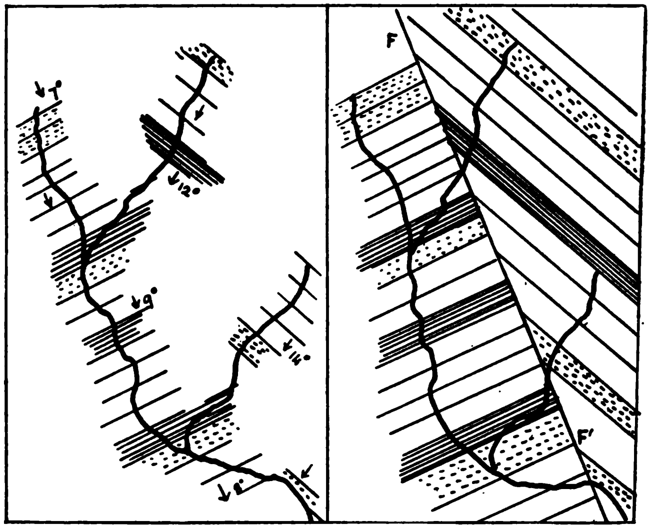

FIG. 32.—Sudden Variation of Strike Produced by a Fault.

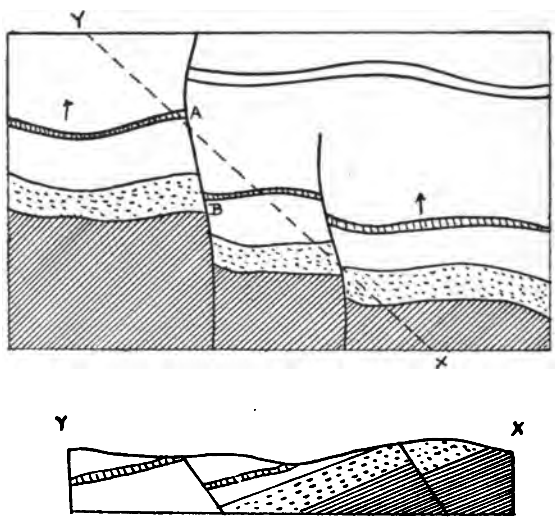

FIG. 33.—Displacement of Outcrop by a Series of Dip Faults.

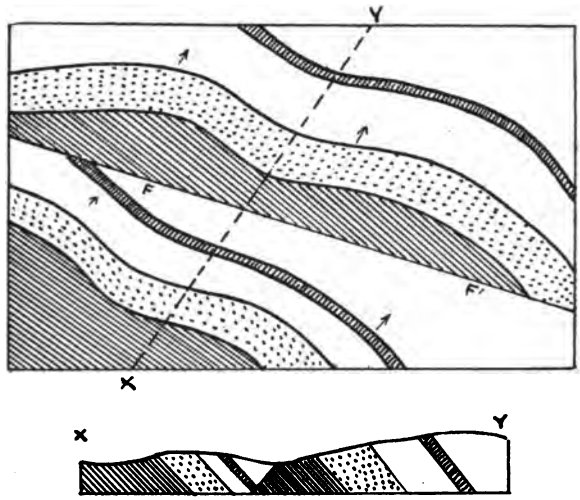

FIG. 34.—Repetition of Strata caused by a Strike Fault.

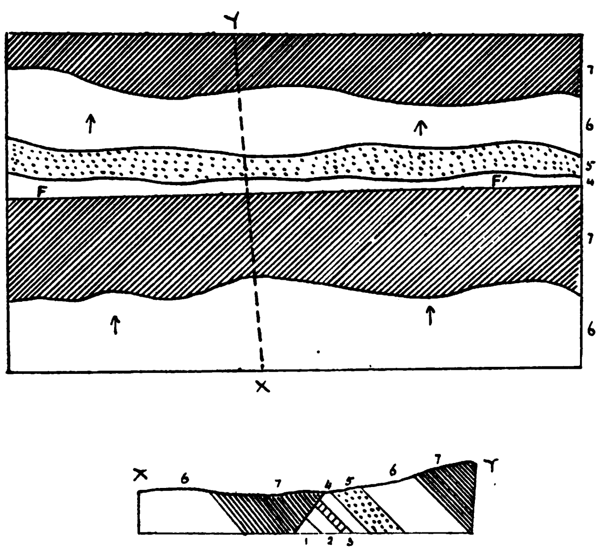

FIG. 35.—Repetition of Strata and Cutting out of Beds by a Strike Fault.

the existence of a line of fault, which is drawn accordingly along the line of deviation *FF'*

(*f*) Dip faults produce a simple shifting of the outcrops, which end abruptly at a certain point and are found again at some distance off in a direction more or less perpendicular to the line of strike. In Fig. 33 we have a map and a section of beds traversed by two parallel faults of this class, the downthrow sides being always displaced in the opposite

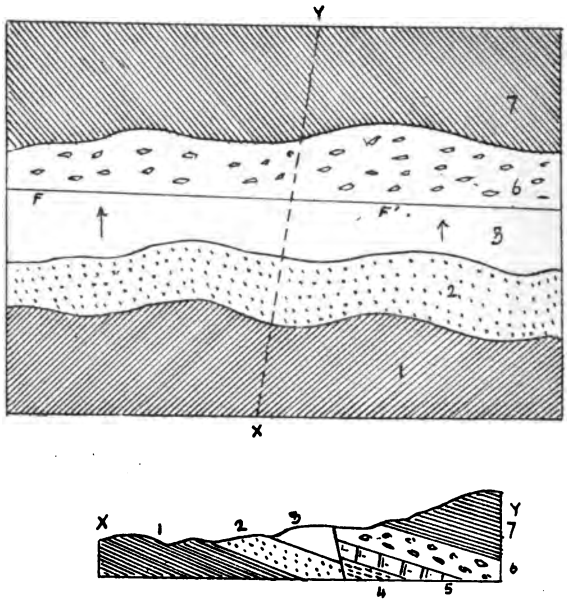

FIG. 36.—Cutting out of Beds by a Strike Fault hading with the Dip.

direction to the dip of the beds in accordance with the rule previously laid down. The section is drawn along the dotted line *XY*.

(*g*) In the case of strike faults, which usually hade against the dip, there is, as we have already seen, no displacement

of the outcrops. There is still the evidence, however, afforded by a repetition of the outcrops on the other side of a line of fault.

In Fig. 34 we have a map and section of strata traversed by a fault of this kind, the strata being exactly repeated *in the same order* on crossing *FF'*, the line of fault.

In some cases it may happen that the repetition is not

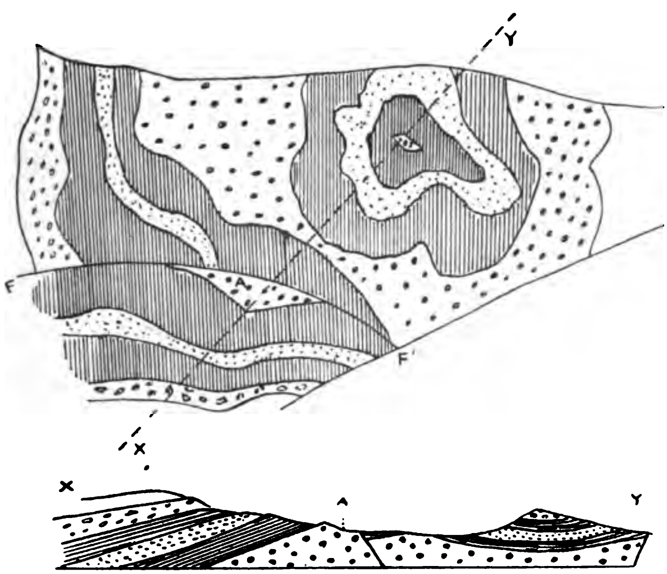

FIG. 37.—Inlier Caused by a Single Fault.

quite in the same order, as is seen in Fig. 35, where the beds 1, 2, 3 are hidden behind the fault, and do not, therefore, crop out on the upthrow side at all.

This cutting out of certain strata is still more complete if the fault should happen to hade with the dip, being also of the normal type, *i.e.* with a hade to the downthrow side. This effect is seen in Fig. 36. In this case there is no repetition of strata at all. Beds 1, 2, 3, 6, 7 follow each

other apparently in unbroken sequence; and only a glance at the section could possibly reveal beds 4, 5, the existence of which might be totally unsuspected unless the true sequence had been previously established from the examination of a wider area free from the dislocation of this kind.

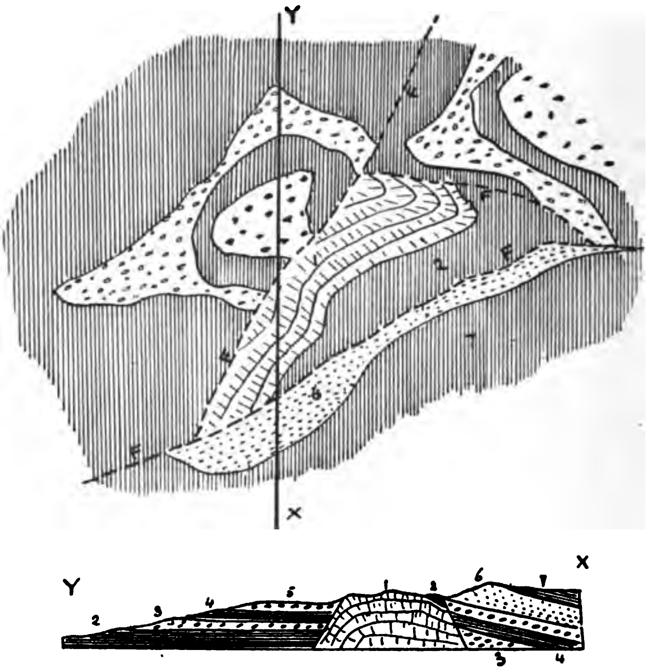

FIG. 38.—Inlier Caused by Intersecting Faults.

Reversed faults, which, as stated above, are usually parallel to the strike, may or may not bring about a repetition of outcrops according to the extent of the displacement. It frequently happens that strata widely separated stratigraphically from one another are brought into juxtaposition by a fault of this class, when of course no repetition of outcrops could be expected.

(*h*) Inliers are sometimes caused by faults. In Fig. 37 the triangular patch marked *A* is seen in the section to have been caused by a single fault with a downthrow to the north-east; while in Fig. 38 we have an inlying patch of beds 1, 2, as the result of a system of three intersecting faults enclosing a triangular space between them. Such an inlier could only be formed by a denuded anticlinal, or by faults; but the position of the strata on the north side of the section precludes the possibility of the former, while the abrupt termination of the outcrops reveals the existence of the latter.

(*i*) In the case of underground seams, a fault may upset all calculations without any surface indications whatever. Even trial borings, if not sufficiently numerous, may result in very erroneous conclusions. Thus, in Fig. 39, borings

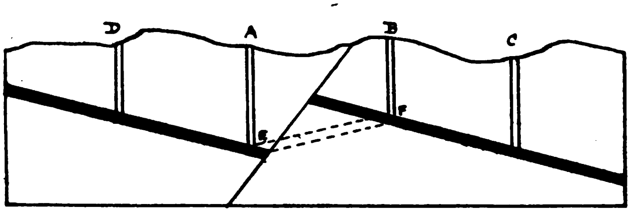

FIG. 39.—Detection of Underground Fault by Trial Borings.

made at *A* and *B* might lead to the supposition that the position shown by the dotted lines *E F* was the true position of the seam, which in reality is traversed by a considerable fault. If other bore holes are made at *C* and *D*, the existence of this fault will at once become evident. This is an additional example of the extreme importance of finding the true dip of beds before entering upon more extensive operations.

Practical Influence of Faults in Mining and Quarrying.—As we have already seen, the bed miner, on coming to a

fault, will find the dislocated seam either above or below him according as he is on the downthrow or the upthrow side. Except in the comparatively rare case of a reversed fault, also, he will find the seam again by following the obtuse angle made by the fault plane with the plane of the dislocated seam. To the vein miner, however, the lateral shift or heave is a more important consideration than the vertical throw, for the reason that mineral veins being usually highly inclined, the dislocated portion must be eventually reached by following the heave, a condition by no means so certain in the case of the less steeply inclined stratified deposits. The same rule, however, generally holds good. By following the greater angle, whether in the horizontal plane, as in vein mining, or in the vertical plane, as in bed mining and quarrying, the interrupted deposit is, in most cases, at length recovered. It is only in the case of reversed faults that this course will be unsuccessful. A rule will be presently given which has the advantage of being applicable to every case.

The amount of barren ground to be traversed between the dislocated ends of the deposit will depend chiefly upon the hade of the fault, a smaller angle of hade giving less barren ground than a hade of larger angle. The importance of this point to the miner needs scarcely to be mentioned, and the reason for the rule is at once evident from a consideration of the diagram, Fig. 40, where *A B* and *C D* represent two faults having different inclinations. The throw of *A B*, measured by *a b* is evidently greater than the throw of *C D*, measured by *c d*, but the heave of the steeper fault *A B*, and the consequent loss to the miner, is much less than that of the more horizontal fault *C D*, the difference being measured by the length of the horizontal line *a c*.

It is often found that the hade of a fault is more nearly vertical in hard strata, and more oblique in soft strata. Where the fault traverses hard and soft strata alternately,

the hade of the fault plane is variable, following a zig-zag course according to the nature of the beds traversed. The shifting which has taken place along such a zig-zag plane produces alternately wide and narrow spaces which have often become the receptacles of valuable minerals. In the Alston Moor lead mining district it is universally found that the steepest parts of such faults contain the richest ore deposits, a result directly following from the fact that the smallest hades are found in the hard limestone strata, and the greatest hades in the soft impervious beds between,

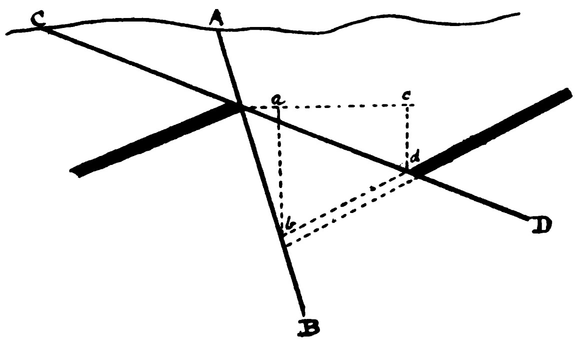

FIG. 40.—Influence of Hade on Lateral Shift.

where the walls of the fault are unfavourable to the accumulation of ore.

Although as a general rule the existence of faults is a cause of loss to the miner, there are cases in which they serve a useful purpose. In many of the coal-fields, for example, the porous strata are so broken up into isolated masses by systems of faults that natural dams are formed by the clay seams faulted against the sandstones, and thus the accumulation of excessive quantities of water is prevented by natural means, where otherwise artificial dams would be necessary. These faults have often a wet side and a dry side, a fact to be carefully taken into account by

the miner before sinking a shaft or penetrating the walls of a fault. In the Cornish mines similar results often follow from the fact that the faults are frequently filled with clay, locally called *flucans*, whereby the surface water is prevented from percolating to so great a depth as would otherwise be the case.

The throwing up of beds by reversed or overlap faults is also a frequent gain to the miner, a fact which is strikingly illustrated in the Witwatersrand gold-fields, where the auriferous conglomerate is continually repeated by a succession of these faults within a small area.

Calculation of the Throw of a Fault. The stratigraphic throw, that is, the distance between the two displaced portions of a bed, measured at right angles to the bedding planes, may sometimes be determined by driving through the fault into the rocks on the opposite side. If the stratigraphic position of these rocks is able to be recognized either by their lithological character or by their fossil contents, a basis is at once found from which the throw of the fault may be calculated. Thus the miner may recognise, on the opposite side of the fault, a stratum which usually occurs at some measurable distance above him. He will then be fairly safe in concluding that the continuation of the displaced seam will be found at this same distance below him.

Knowing the dip of the beds and the hade of the fault, the throw can then be calculated either by plotting a diagram to scale or by mathematical calculation. The graphic construction is at once seen from the diagram, Fig. 41, where θ represents the dip of the seam, and ϕ the hade of the fault. If AD be drawn, representing on any scale the stratigraphic throw, the throw of the fault is at once got by scaling off AB. Trigonometrically, we have $AC = AD \sec(\theta+\phi)$, and $AB = AC \cos\phi = AD \cos\phi \sec(\theta+\phi)$, which determines the throw in terms of the stratigraphic throw.

It is sometimes possible to obtain the throw of a fault from surface observations only, in which case the displacement of the outcrop must be accurately mapped and the dip of the beds measured. The distance is then measured on the ground between the termination *A*, Fig. 33, of the seam on the upthrow side, to the nearest point *B* of the same seam on the downthrow side, the fall of the ground between these two points being carefully noted. From the

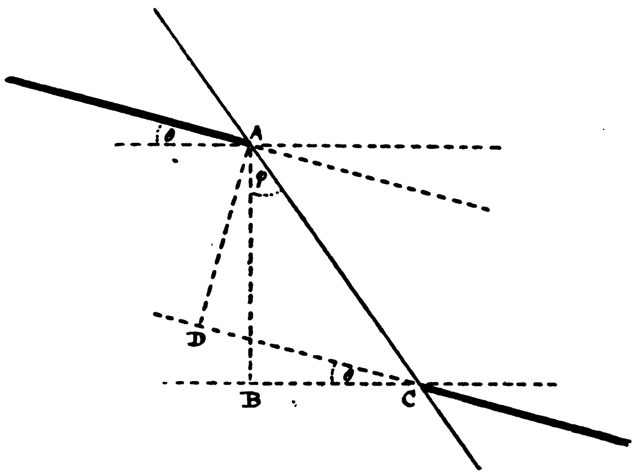

FIG. 41.—Calculation of the Throw of a Fault.

dip diagram, given in Chapter II., it is then found how deep a boring would require to be made at the point *A* to reach a seam dipping from *B* at the known distance from *A*.

This depth, plus or minus the fall in the ground as the case may be, will obviously be the amount of downthrow at the point *A*.

Search for Dislocated Veins: Zimmermann's Rule. The rules which have already been given for fixing the position of a dislocated vein or seam cannot be applied in every case, as it is not always possible to be certain that a fault

is of the normal type. The problem is simplified to a great extent if the exact position can be determined in which the fault plane intersects the plane of the deposit, that is, if we can find the dip and strike of the line of intersection of these two planes, a problem of practical importance in mining since the line of intersection of two mineral veins is often the position of the richest ore deposit. Knowing the dip and strike of each of the two planes, their line of intersection is obtained by the following simple graphic construction, it being obviously immaterial whether these two planes are veins, seams, cross-courses or fault-planes.

The known strikes of the two planes are first plotted. Let these be represented by AB and CD, Fig. 42. Let

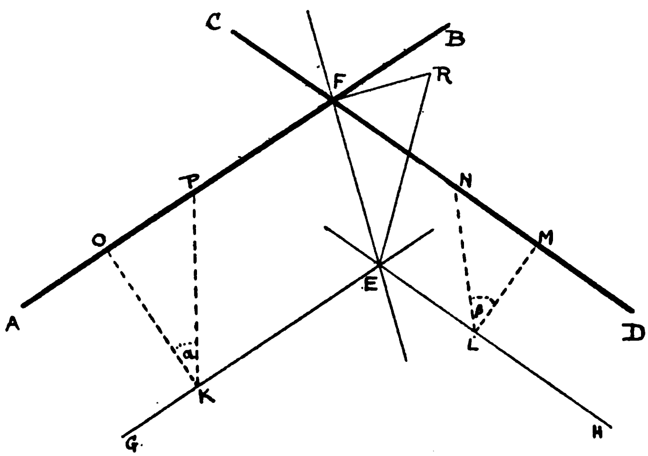

FIG. 42.—Line of Intersection of two Planes by Graphic Construction.

the dip of the plane AB be α, and the dip of CD be β. At any point O in AB a perpendicular is drawn *in the direction of the dip*, and at any convenient point K in this perpendicular the angle OKP is constructed equal to α, the angle of dip. At any point M in CD a perpendicular

is drawn, also in the direction of the dip of the plane *CD*, and *MN* being made equal to *OP*, *NL* is drawn so that the angle *NLM* is equal to β. Through the points *K* and *L* the straight lines *GE* and *EH* are drawn parallel to *AB* and *CD* respectively. Let these parallels intersect at *E*, and join *EF*.

Then *EF* is the direction of the strike of the intersection of the planes *AB* and *CD*.

The dip of this line of intersection is easily found by making the right-angled triangle *EFR*, of which *FR* is equal to *OP*. Then *FER* is the angle of dip required.

So many important problems depend upon this question that a trigonometrical solution is now given, although the above construction is of much greater practical utility.

In Fig. 43 the point *E* is obtained by the same con-

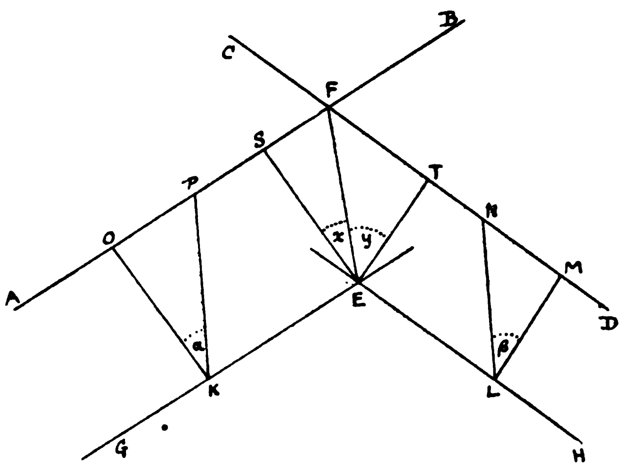

FIG. 43.—Line of Intersection of two Planes by Formula.

struction as above, and *ES* and *ET* are drawn at right angles to *AB* and *CD* respectively. Let the angle *AFD* $=\delta=180^\circ-(x+y)$.

Then we have $ES = OP \cot \alpha = EF \cos x$,

and $ET = OP \cot \beta = EF \cos y$,

whence $\frac{ES}{ET} = \frac{\cos x}{\cos y} = \frac{\cot \alpha}{\cot \beta}$.

By a well-known methematical artifice we have $\frac{\cos x + \cos y}{\cos x - \cos y} = \frac{\cot \alpha + \cot \beta}{\cot \alpha - \cot \beta}$, whence we easily derive the formula $\cot \frac{x-y}{2} = \frac{\sin (\alpha + \beta)}{\sin (\alpha - \beta)} \tan \frac{x+y}{2} = \frac{\sin (\alpha + \beta)}{\sin (\alpha - \beta)} \cot \frac{\delta}{2}$, whence x and y are obtained.

In a similar manner, if θ be the angle of dip of the line of intersection, we find $\tan \theta = 2 \frac{\sin \alpha \sin \beta}{\sin (\alpha + \beta)} \sin \frac{\delta}{2} \cos \frac{x-y}{2}$.

Example.—The strike of a vein is 101° 15′, and its dip 80° S. Find the strike and dip of the line of its intersection with a fault plane of which the strike is 170° 37½′ and the hade 15° W.

[*Answer.*—The strike is 62° 27½′ and the dip 74° 15′ 26″.]

Knowing the strike and dip of the line of intersection of two lodes by means of either of the above methods, a heading can be accurately driven along this line, where the richest ores are often found.

We have now to see how the above construction assists in the search for veins or seams dislocated by faults. In Fig. 44 we have two dislocated portions of a seam, represented by *AH* and *BK*. In whichever portion the miner is working, on coming to the interruption, he will first find the strike of the line of intersection of the seam and dislocator. Let *CD* or *EF* be this line, according to the miner's position at *A* or *B*. He now draws a line at right angles to the strike of the dislocator, and directed away from himself towards the inside of the dislocator. He then seeks for the lost seam by following along the dislocator in that direction in which the perpendicular deviates from the strike of the line of intersection *CD* or *EF*. Thus the

seam lost at *A* will be found towards *B*, and the seam lost at *B* will be found towards *A*. The full construction for this rule, due to Zimmermann, is given by the following worked example. On driving a lode *FC* towards *C*, it is

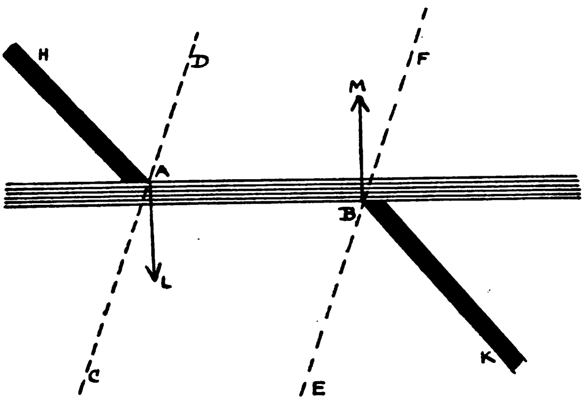

FIG. 44.—Zimmermann's Construction for Dislocated Lodes.

found that the lode ends at *C*, having been displaced by a fault *AB*, having a strike of 65° and a dip of 30° S. 25° E. The lode has a strike of 120°, and a dip of 20° N. 30° E.

The line of intersection of the lode and fault is first found by the construction already given. This line is shown in Fig. 45 by *XY*, the full construction being given by dotted lines. At *C* a perpendicular is drawn to *AB*, the line of strike of the fault. This perpendicular deviates from *CX* towards the right of *CF*. The dislocated lode will, therefore, be found by driving along *AB* towards *B*. In this case, by adopting the course of following the greater angle, the search would have been continued towards *A* with a futile result.

The above rule is sometimes stated thus: the heaved part of the vein should be looked for on that side on which the plan of the intersection makes the largest angle with the plan of the fault.

It is clear that Zimmermann's construction could not apply in the case of a strike fault, since the strikes of vein and fault do not intersect, being parallel to one another.

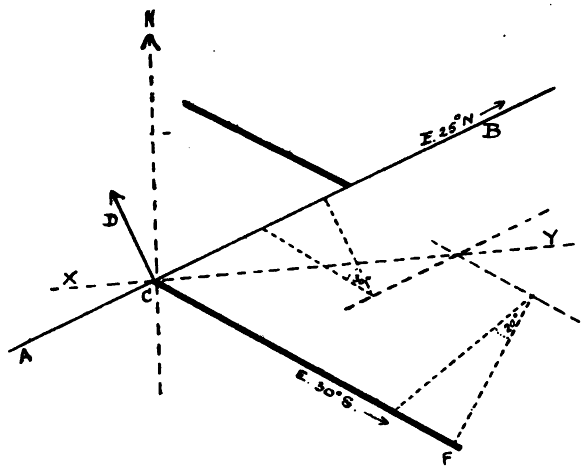

FIG. 45.—Zimmermann's Construction, Worked Example.

When the fault fissure is bent, and the beds contorted, the above problems become extremely complex, but the consideration of such complications would carry us far beyond the limits of these pages.

CHAPTER V

Economic Minerals—Stratified Ore Deposits—Placer Gold and Platinum Deposits—Stream Tin—Iron Sands—Bog Iron Ore—Clay Ironstone—Manganese Beds—Bauxite—Red Hæmatite—Magnetite—Copper Shales—Metalliferous Sandstones—Witwatersrand Gold Conglomerates.

Economic Minerals.—Having now described, in their practical bearing, some of the more important geological conditions under which the stratified rocks occur in the earth's crust, there still remain to be considered the various phenomena connected with irregular or unstratified deposits. The treatment of these will be best undertaken in connection with the special branches to which they more particularly apply, beginning with the application of geology to the important industries of mining and quarrying.

Before the prospector endeavours to discover new situations favourable for the extraction of valuable minerals, he should first make himself thoroughly familiar with the circumstances under which such deposits are already known to occur. An actual survey of even the chief mining and quarrying districts of the world is of course impracticable. Even those of a single country would require for their study a larger expenditure of time than could generally be devoted to such a task. Written descriptions, even when illustrated by diagrams, can scarcely be expected to replace the actual investigation of typical mines and quarries, but such descriptions are nevertheless useful so far as they serve to summarise the geological characters which should be looked for in the field by those who are in search of mineral treasures, and so long as they are not made a substitute

for that practical experience which alone can form the basis of success.

At the outset we are here met by some difficulty as regards classification, owing to the great variety of substances with which we have to deal and the many different ways in which they have been formed. Some of the minerals in question occur in stratified beds, others in irregular seams or veins; some are obtained by quarrying in open works, others by mining; some are used for the extraction of metals, others are of an earthy or saline nature; but not one of these characters is altogether satisfactory as a basis for a scheme of classification. The present chapter will be confined to the consideration of those metalliferous minerals, or ores, which occur in stratified beds.

Stratified Ore Deposits.—An ore may be defined as any mineral substance which contains a workable proportion of metal in a strictly economic sense, a definition which doubtless excludes many substances not now worked as ores, but which, owing to improved metallurgical processes, may become valuable sources of metal at some future time.

It has been shown by the researches of Sandberger and others that traces of nearly all the common metals, and even of some rarer ones, occur disseminated through the rock-forming minerals of the earth's crust. Ore deposits, therefore, may be looked upon as a concentration of these scattered particles in certain places such as in the beds of rivers and lakes, and in the joint planes, fault planes and solution cavities in rocks. The agency by which this concentration has been brought about may have been either of a mechanical or chemical nature, in each of which water has played the chief part. The stratified ore deposits occur in beds or seams, usually only slightly inclined and uniform over large areas. They have invariably been formed contemporaneously with the enclosing rocks, for which reason it has been suggested by Prof. H. Louis to call them *sym-*

phytic deposits, to distinguish them from those ores which have become subsequently infiltrated into irregular fissures and cavities, for which he proposes the term *epactic.*

It is usual to subdivide the stratified ore deposits according to their mode of origin as follows :—

STRATIFIED ORE DEPOSITS.

Mode of formation.	*Typical examples.*
a. Clastic, or mechanically-formed deposits.	Placer gold and platinum deposits. Stream tin. Iron sands.
b. Precipitation from aqueous solutions.	Bog iron ore. Clay ironstone. Manganese beds. Bauxite.
c. Metamorphosed precipitated deposits.	Red hæmatite. Magnetite.
d. Disseminations through sedimentary rocks.	Copper shales. Metalliferous sandstones. Witwatersrand gold conglomerates.

Placer Gold and Platinum Deposits.—These deposits of alluvial gold and platinum have been formed by the breaking up of older rocks under the influence of subaerial denudation, and the redeposition of the heavy metallic particles with the gravels and sands carried down by rivers. The rivers themselves have in fact done the work of breaking up, pulverising and washing the contents of the mineral lodes from which these gravels have been mainly derived, performing at once the duties of stamp mill and concentrator, and thus effecting a considerable saving of labour and expense to the miner. Only those metals which by their chemical durability are enabled to withstand the prolonged action of water without oxidation would be expected to occur in such alluvial beds. Placer gold deposits may be either shallow, superficial gravels of comparatively recent geological age, or more ancient river gravels,

often silicified and protected from denudation by overlying beds of volcanic rock. Fig. 46 represents a generalised

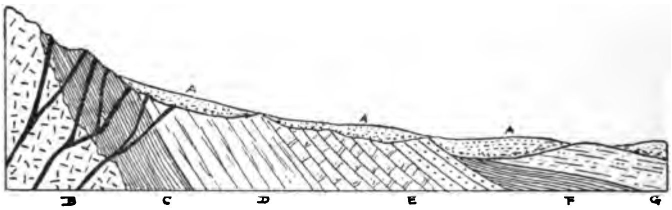

FIG. 46.

section through the Ural Mountains, where the gravel beds, *A*, contain the gold derived from the quartz veins in the older rocks, *B*, *C*. A considerable part of Californian gold is derived from an old river gravel which has been preserved beneath a lava stream, as shown in Fig. 47, where the

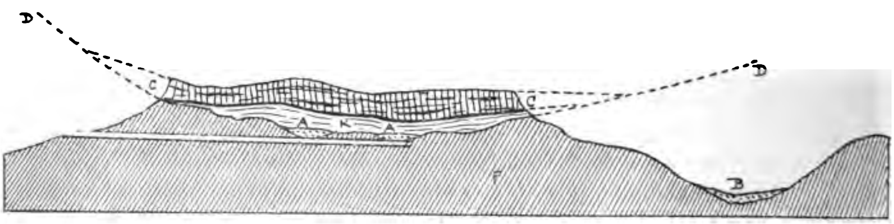

FIG. 47.

dotted line *DD* represents the outline of the old river valley in which the auriferous gravel, *A*, was deposited, the preservation of the gravel being due to the protective action of the volcanic rock *C*. A very similar state of things is found in some of the Australian goldfields, as shown in the section, Fig. 48, where the gravel patches, *A*, are buried beneath a thick lava flow *B*. The ease with which the superficial gravels can be worked, and their local richness in gold usually lead to their rapid exhaustion, but the deep placers, or *deep leads*, of California and Victoria are still a most valuable source of the precious metal. One of the oldest known auriferous gravels is found in the Black

Hills of Dakota, in a conglomerate of a Lower Silurian age, derived from still more ancient palæozoic schists. Platinum has hitherto been found almost exclusively in alluvial gravels, often associated with gold. Its distribution, however, is much more limited, about five-sixths of the world's supply being derived from the gravels of the Ural Mountains alone.

The occurrence of large pieces of gold, or nuggets, in placer deposits has often been urged as a proof that these have "grown" *in situ* from chemical action subsequently to the deposition of the beds. It seems more probable, however, that they have resulted from a mechanical welding

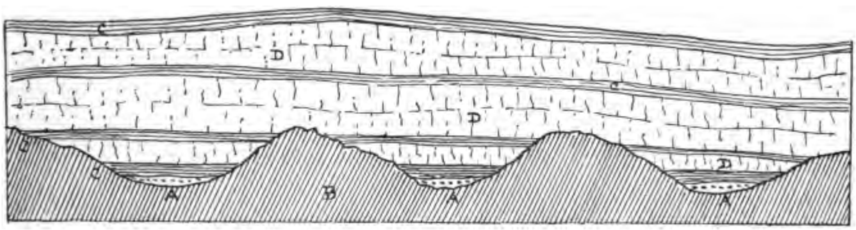

FIG. 48.

of smaller fragments during the mechanical movements which have brought down the gravels. Placer gold is generally purer than that found in veins; but this does not imply a different origin, being rather the result of chemical action whereby the impurities have been oxidised and removed by the water percolating through the permeable gravels. Auriferous pyrites, for instance, would speedily become decomposed, a residue of metallic gold being left behind. This natural process of oxidation can be shown in actual progress in many gold-bearing quartz reefs, where the gold is found in a pure state above the water line, but below this line it is so intimately associated with metallic sulphides that special methods have to be adopted for its extraction.

Wherever these gravels occur it may fairly be assumed

that the rocks from which they have been derived contain the source whence the metal has been obtained, although the search for this source has not always proved successful. Thus in the Ural Mountains but very little platinum has been found in the older rocks from which the platinum bearing gravels have been derived. The small quantities of alluvial gold found in Wicklow and Sutherland, also, have not yet led to the discovery of auriferous quartz veins in the older rocks. Such failures are not surprising when it is remembered that considerable quantities of metal may be concentrated by accumulation in gravels during long geological periods, even when only minute quantities are present in the parent rocks. The mere finding of detrital gold or platinum, therefore, is not in itself a proof that paying quantities will be found in the adjacent hills.

Stream Tin.—Extensive beds of detrital tin-ore are found in gravels derived from stanniferous rocks. This tin-ore, the oxide known as cassiterite (SnO_2), is the only source of tin, and is abundantly distributed, chiefly in granite, throughout the world, although it can rarely be profitably mined unless concentrated in river gravels. Tin stone, as this ore is called, has a specific gravity of 6·8, and is very indestructible under the influence of meteoric agencies, to which properties it owes its abundant accumulation in placer deposits or stream works. In Cornwall tin streaming was formerly carried on on an extensive scale, but the gravels are now exhausted. The most important source of tin at the present time is in the alluvial deposits of Malaysia, where the tin-bearing gravels are found beneath an overburden of clay, sand or gravel varying from 20 feet to 80 feet in thickness. The accompanying section, Fig. 49, shows the common mode of occurrence of tin ore in the island of Banca, the bed rock consisting of clay, derived from the decomposing granite, or limestone in which rich deposits of ore often fill pot-holes to a considerable depth. As in the case of gold and platinum, stream tin is of a

purer description than vein tin, owing to the decomposition of the metallic sulphides and arseniates often accompanying the latter, a circumstance of considerable importance in practice. It is doubtful whether the elementary metallurgical methods known to the natives of the East Indies would have enabled them to deal with the ore in any other form.

The dull brown water-worn pebbles of tin stone may easily be mistaken for iron, and it is possible that many deposits of stream tin remain yet to be discovered.

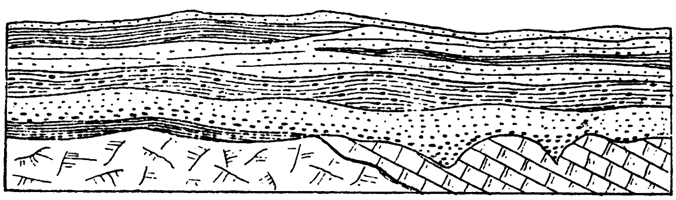

FIG. 49.

Iron Sands.—The rivers flowing from the Deccan trap rocks often contain enough magnetic iron sand to furnish material for native iron furnaces. Even beach deposits have been known to contain finely divided metallic ores in a sufficiently concentrated state to repay the miner. Of such a nature are the black sands containing titaniferous iron found in the Bay of Naples, as well as in Labrador, New Zealand and California, the last two containing also gold in workable quantities. Occasionally the beach sands of the Malay peninsula contain a large percentage of tin ore, mixed with titaniferous iron, the separation of which, however, has proved too difficult for the crude native methods of mining.

Enough has now been said to show the importance of superficial detrital deposits as a source of valuable metals. The concentration which has resulted from the prolonged

mechanical action of water has resulted not only in the accumulation of ores, but also in their purification by the disintegration of the less stable minerals which accompanied them. We have now to consider an important class of deposits which has resulted from chemical action alone chiefly upon the compounds of iron and manganese.

Bog Iron Ore.—The chemistry of the natural processes by which stratified iron ores are produced affords an instructive example of the chemical changes which are in constant progress in the rocks of the earth's crust. The wide distribution of iron in rocks of every age and in nearly every species of rock-forming mineral is a fact sufficiently well known to every student of geology. When concentrated into workable beds of iron ore these usually occur in the varieties shown in tables on next column.

To understand fully the chemical changes which have brought about the concentration of iron into beds or seams is a useful lesson in geological chemistry. If we consider first the silicates of iron as they occur disseminated in various minerals throughout the crystalline rocks, we find that although the persilicates are not readily attacked by carbonic acid, they are easily reduced to protosilicate under the influence of natural reducing agents such as decomposing organic matter. Now the protosilicates of iron are not only converted by water and carbonic acid into a soluble carbonate, but are also to some extent dissolved unchanged and deposited as the green colouring matter of many rocks in the form of *green earth* or *glauconite*. This conversion of protosilicate of iron may be seen in actual progress in many places where ferruginous sands are covered by vegetable soil. The humic and crenic acids, derived from the decaying vegetation, not only dissolve and remove the ferric oxide forming the red colouring matter of many sands, but the green colour, also, due to the presence of glauconite, is replaced near the surface by yellow and red tints, showing the alteration of the silicate into peroxide. The silica, thus

set free, is often to be noticed cementing the sands into nodular concretions.

The sulphides of iron, also, and especially the form known as *marcasite*, pass by oxidation into soluble ferrous sulphate, often present in chalybeate waters, which not only possess, on that account, an inky taste, but also deposit beds of

CHIEF IRON MINERALS.

(*a*) *Used as Ores of Iron.*

Ore.	Chief Varieties.	Remarks.
1. Magnetite (*ferroso-ferric oxide* $FeO.Fe_2O_3 = Fe_3O_4$)	Magnetic oxide of iron (Fe_3O_4). Chrome iron ($FeO.Cr_2O_3$.)	Black streak; strongly magnetic. Abundant in serpentine rocks; found occasionally in black sands.
	Titaniferous iron, or ilmenite ($FeTiO_3 + Fe_2O_3$).	Common in igneous rocks; a common constituent of black sands; feebly magnetic.
2. Red Hæmatite (*Anhydrous sesquioxide*, Fe_2O_3)	Specular iron. Micaceous iron. Kidney iron. Fossil hæmatite. Reddle and ochrey iron ore. Jaspery, columnar and lenticular clay iron.	Cherry-red streak; often mixed with earthy impurities; colour varying from deep red to iron black.
3. Brown Hæmatite (*Hydrated sesquioxide* $2Fe_2O_3.3H_2O$)	Limonite. Bog iron. Yellow ochre. Göthite ($Fe_2O_3.H_2O$).	Streak ochre-yellow to light brown; often concretionary; earthy impurities common.
4. Spathic Iron (*Ferrous carbonate*, $FeCO_3$)	Siderite or chalybite. Sphærosiderite. Clay ironstone. Black band.	Brown streak; often concretionary; generally contains some manganese carbonate (diallogite); often argillaceous.

(*b*) *Not used as Ores of Iron.*

Ore.	Chief Varieties.	Remarks.
5. Iron Pyrites. (*Sulphide of Iron* FeS_2)	Mundic (FeS_2).	Grey streak : often auriferous : yellow.
	Marcasite (FeS_2).	Readily decomposed ; paler than mundic.
	Pyrrhotine (Fe_7S_8).	Slightly magnetic : bronze yellow.
	Mispickel (FeSAs).	Tin-white colour.
6. Phosphate of Iron, $Fe_3(PO_4)_2$	Vivianite.	Bluish streak earthy.
7. Silicates of Iron.	Green earth. Glauconite.	Forms the green colouring matter of many rocks.

ochre or limonite for a considerable distance from their source. On coming into contact with soluble carbonates, ferrous sulphate becomes converted into ferrous carbonate or spathic iron, which was artificially produced in the laboratory by this means by de Sénarmont. These facts sufficiently explain the great abundance of ferrous carbonate in natural waters.

Now ferrous carbonate, called also *spathic iron* or *siderite*, is converted by the action of air and water into *brown hæmatite*, the change being represented by the following chemical equation :—

$$\underset{\text{spathic iron.}}{4\,FeCO_3} + O_2 + 3H_2O = \underset{\text{brown hæmatite.}}{2Fe_2O_3.3H_2O} + 4CO_2.$$

Thus chalybeate waters, containing ferrous carbonate in solution, when exposed to the air, soon exhibit upon their surface a thin iridescent film of brown hæmatite, which gradually settles down into a layer of bog iron ore such as frequently accumulates on the bottom of marshy swamps or lakes. Frequently this deposit takes the form of roe-like grains or pisolitic ore, and porous sands become cemented by it into ferruginous concretions. In Finland and Sweden

the lakes are regularly dredged for the concretionary iron ores which are continually forming in the neighbourhood of the rush banks. The influence of decaying organic matter is important, for it is only the protosalts of iron, formed by reduction of the persalts, which are capable of undergoing this transformation under the combined solvent influence of carbonic acid, and the organic acids, such as humic and crenic acids, yielded by the decay of vegetation. It is not surprising, therefore, that those geological periods which are notable for luxuriant vegetable growth are also those which contain the richest deposits of iron ore. Of the innumerable examples of iron ores formed in this way, the accompanying section, Fig. 50, is a typical instance,

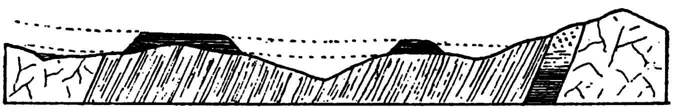

FIG. 50.

and represents the famous ironstone deposits of Rio Tinto, in Spain, where a lode of iron pyrites, by oxidation at the surface, furnished the soluble iron salt which was subsequently deposited as brown hæmatite upon the bottom of a lake now extinct.

The value of such bog iron ores is frequently diminished by the presence of a large amount of phosphorus and other impurities.

Clay Ironstone.—The ease with which ferrous carbonate passes by oxidation into the hydrated sesquioxide makes it somewhat difficult to account for the common occurrence of spathic iron ore in many of the older stratified formations. The oxidation may, however, have been prevented by an excess of organic matter, or by want of access to the air. Water and carbonic acid, also, containing ferrous carbonate in solution, would precipitate spathic iron on coming into contact with calcium carbonate. The common

occurrence of this ore in beds of calcareous clay points to such an origin. Thus the Northampton ironstone was probably originally a sandy oolitic limestone into which either soluble organic ferrous salts or the bicarbonate of iron percolated. Double decomposition then took place between the calcium and iron salts, resulting in the replacement of calcium carbonate by ferrous carbonate, and the removal of calcium salts in solution, thus:—

$$\underset{\text{soluble ferrous bicarbonate.}}{FeH_2(CO_3)_2} + CaCO_3 = \underset{\text{spathic iron.}}{FeCO_3} + \underset{\text{soluble calcium bicarbonate.}}{CaH_2(CO_3)_2}$$

The spathic iron has, in this case, been gradually converted into limonite in its upper portions, under the influence of atmospheric oxidation.

Spathic iron ore occurs most abundantly in beds and concretionary nodules in the coal measures of England and the continent. The famous Cleveland iron ore is also mainly composed of argillaceous carbonate, and immense deposits have been worked from the earliest times in Styria, Carinthia and Rhenish Prussia. The well-known "*black band ironstone*" of North Staffordshire and Scotland contains such an admixture of bituminous matter that it can be calcined without extra fuel.

The common tendency of iron ores to aggregate into large or small concretions is very characteristic of many minerals, and the explanation is still an unsolved problem in chemical geology. Frequently a fossil has formed the nucleus around which the concretion has grown in concentric layers. Thus the sphærosiderites, or the clay ironstone concretions of the coal measures, frequently enclose ferns and other organic remains.

Manganese Beds.—Manganese is not only closely associated with iron in its chemical properties, but it is also very similar to it in its geological occurrence and distribution. The table on next page shows the composition of the chief

TABLE OF MANGANESE ORES.

Ore.	Composition.	Remarks.
1. Pyrolusite . .	Manganese dioxide (MnO_2)	Brown-black streak; radiated.
Psilomelane . .	Hydrated form of above .	Brown-black streak; amorphous.
Wad or bog manganese	Impure variety of above .	Greyish-brown streak; earthy.
2. Hausmannite .	Manganous-manganic oxide (Mn_3O_4)	Brownish-red streak.
3. Braunite . . .	Manganese sesquioxide (Mn_2O_3).	Brown streak.
Manganite . .	Hydrated form ($Mn_2O_3.H_2O$)	Deep brown-red streak.
4. Diallogite . .	Manganese carbonate ($MnCO_3$)	Pinkish-white streak; flesh coloured; hardness 4.
5. Rhodonite . .	Manganese silicate ($MnSiO_3$).	As above; hardness 5½.
6. Wolfram . . .	Tungstate of iron and manganese.	Characteristic lustre and cleavage.
7. Franklinite . .	Triple oxide of iron, manganese and zinc.	Used first for extraction of zinc, afterwards for spiegeleisen.

ores, some of which are, however, too rare to be of great use.

The well-known dendritic form of earthy manganese oxide, called *wad* or *bog manganese*, is shown in Fig. 51, and its presence is often indicated by these fern-like markings and brownish black stains on the fissures and joint planes of rocks. Like iron it frequently forms concretionary nodules, which may become still further concentrated by the decay of the enclosing rock. An interesting example of such a process is seen in the manganese-bearing clay

deposits of Arkansas, which have been left as a residual soil by the solution of Silurian limestones containing man-

FIG. 51.

ganese concretions. Fig. 52 shows its mode of occurrence

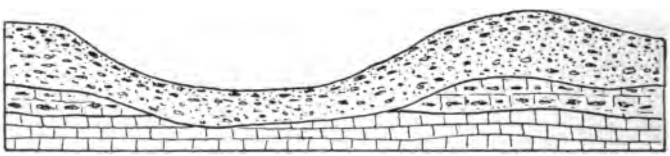

FIG. 52.

in a manner very suggestive of the clay-with-flints so often formed on the chalk districts of England by the solution of calcium carbonate.

The frequent association of manganese and iron is of economic importance owing to the superior quality of the steel made from manganese-bearing iron ores. The spiegeleisen made from the spathose iron ore of the Brendon Hills, Somersetshire, owes its qualities to an admixture of about 13 per cent. of manganous oxide. Fig. 53 shows a

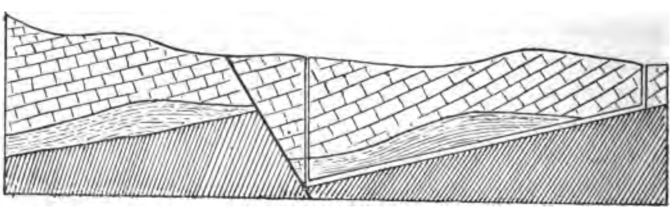

FIG. 53.

similar association of manganese and hæmatite at Nant Uchaf, North Wales. The important beds of manganese occurring in the Caucasus, and represented in Fig. 54, con-

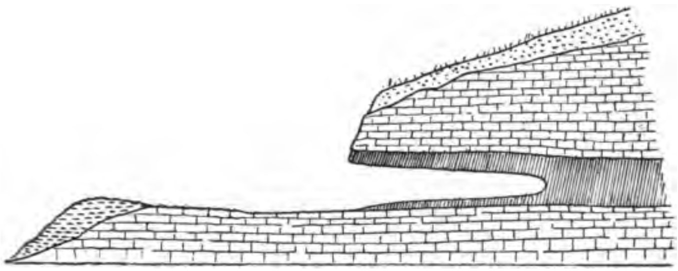

FIG. 54.

sist chiefly of pyrolusite and manganite, in nearly horizontal layers in Eocene limestone.

When we consider the abundance of concentric nodules of pyrolusite which occur scattered over the ocean bed, and which undoubtedly owe their origin to the decomposition of volcanic rocks containing manganese-bearing minerals, there is little difficulty in accounting for the presence of this ore in the stratified rocks. The same chemical changes which have operated in the production of the iron ores mentioned above would also result in the conversion of manganese carbonate into pyrolusite, psilomelane, and wad. These changes can be seen taking place in some of the Welsh manganese beds, where the carbonate at lower levels becomes converted into hydrous oxides near the surface.

Bauxite.—The ores of aluminium, which can be profitably used in the production of the metal, are few in number and limited in distribution. The anhydrous oxide, *alumina*, occurring in the form of corundum or emery, and in the rarer forms of ruby and sapphire, are too valuable to use as an ore of aluminium. The hydrous oxides, *diaspore* and *Gibbsite*, are of comparatively rare occurrence. The hydrous sulphate of alumina, known as *aluminite* or

Websterite, is not of common occurrence; and the double fluoride of aluminium and sodium ($Al_2F_6.6NaF$), called *cryolite*, although formerly the chief source of the metal, is almost exclusively confined to Greenland.

Bauxite, the chief source of aluminium at the present time, is a hydrated oxide having the composition $Al_2(HO)_6 + Fe_2O_3$. It may, therefore, be described as limonite in which part of the iron has been replaced by aluminium. This mineral was first discovered in Baux, a village of South France, where it occurs in beds, nodules and grains in limestone rocks. It has probably been formed in a similar manner to limonite by precipitation in lakes and lagoons. Since its original discovery it has been found in Italy, Austria, Ireland, Alabama, Georgia and Arkansas, and in Germany as a product of decomposition of basalt. In Ireland it occurs in the iron ore measures of Antrim, between the upper and lower sheets of basalt.

The occurrence of this native hydrate of alumina is to be explained by the well-known method of extracting alum from pyritous shale. The hydrous aluminium silicate of which clay is composed is readily converted into sulphate by the action of ferrous sulphate formed by the oxidation of iron pyrites. This change goes on spontaneously in alum shales exposed to the air. The sulphate of alumina thus formed is easily converted into the hydrated oxide by the action of potassium or calcium carbonates. It is perhaps, therefore, somewhat surprising that this mineral has not yet been more abundantly found.

Red Hæmatite and Magnetite.—In many cases beds of precipitated iron ore have become altered by the subsequent metamorphism of the rocks with which they are associated. The first result of such an action would be a loss of water whereby the original hydrated sesquioxide, or brown hæmatite, would pass into the anhydrous forms of red hæmatite or magnetite. That such was the origin of some at least of these ores is proved not only by their occurrence in

well-defined beds, but also by the occasional presence in them of fossil remains. In most cases, however, all trace of the original condition of the ore has been obliterated by metamorphic action. A good instance of such a bedded magnetite deposit is shown in Fig. 55. The famous Pilot

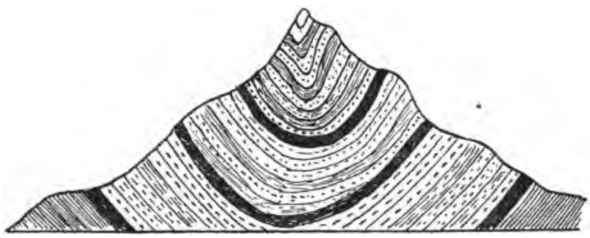

FIG. 55.

Knob iron ore of the United States is a specular hæmatite occurring in a thick bedded seam nearly 50 feet in thickness, and bearing distinct evidence of being a highly metamorphosed stratified deposit.

In accounting for the change it must be remembered that most of the iron ores become magnetic under the action of heat. We must look upon magnetite as a definite chemical combination of protoxide and peroxide of iron in the proportions represented by the formula $FeO.Fe_2O_3$. If, therefore, a brown hæmatite be heated, it first loses water and becomes red hæmatite, and then by partial reduction magnetite may be formed. If, again, siderite be roasted, octahedral crystals of magnetite can be artificially produced, thus—

$$\underset{\text{siderite.}}{6FeCO_3} + O_2 = \underset{\text{magnetite.}}{2FeO.Fe_2O_3} + 6CO_2$$

We have now seen the complete cycle of change which the iron ores undergo in nature. In the crystalline rocks the iron occurs in the state of anhydrous peroxides. These, being reduced to protoxide, are attacked by carbonated waters and carried away in solution as protocarbonate,

which in its turn becomes oxidised to form the hydrous peroxides, or brown hæmatites. By the action of heat these last become dehydrated, and pass again into their original forms of red hæmatite and magnetite.

Copper Shales.—An important class of stratified ore deposit is that in which a workable proportion of metallic ore has been introduced in a state of solution either contemporaneously or subsequently to the formation of the beds themselves. Such beds are generally richer in ore when highly inclined, or in the neighbourhood of faults or igneous dykes, such conditions being more favourable to the circulation of subterranean water impregnated with metallic salts.

Such a deposit is the copper-bearing shale (Kupferschiefer) in the Permian formation of Mansfeld, in Saxony, where sulphide of copper is disseminated in microscopic particles throughout the bituminous shale with great regularity for many miles. It is a noteworthy fact that Permian strata in widely separated localities are characterised by the presence of copper ores, such deposits being known also in Russia, Great Britain and America. Most of the Lake Superior copper is obtained from beds of conglomerate or sandstone in which the cementing material is native copper, evidently deposited from aqueous solutions permeating the strata. There is evidence to show that in some cases such deposits have resulted from the reduction of copper sulphate by the decomposition of organic matter. Fig. 56

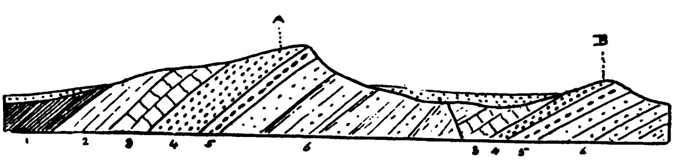

FIG. 56.

shows the mode of occurrence of copper ore at the base of the Keuper beds in Cheshire. The ore is here in the form

of malachite and azurite, the green and blue carbonates, which are disseminated through the cementing material of the quartz conglomerate.

Metalliferous Sandstones.—Another example of the same class of deposit is the silver sandstone of Utah, where Triassic sandstones are impregnated with silver chloride and sulphide to the extent of 25 ounces to the ton. The distribution of the silver, in this case, seems to have been largely determined by the ease with which percolating waters from below could penetrate the sandstone, the ore being scarce or absent where such percolation is impeded by impermeable seams. Of the same nature is the lead-bearing Triassic sandstone of Commern, in Rhenish Prussia, in which concretions of quartzose sand are cemented by galena, the overlying conglomerates containing pebbles coated with the same substance. The well-known Spanish quicksilver mines of Almaden are in stratified sandstones impregnated with cinnabar, as also are those of Idria and Ekaterinoslav. There appears to be no doubt but that the metal has been deposited from mercurial solutions from below.

Witwatersrand Gold Conglomerates.—Perhaps the most interesting deposits of this nature are the gold-bearing conglomerates of the Witwatersrand. These conglomerates, locally called "*banket*" reefs, are thin beds of quartz pebbles cemented with a siliceous and partly ferruginous cement. They dip at high angles, and are interstratified with sandstones and grits. The gold occurs in sharp-edged crystals in the cement, and cannot, therefore, have been subjected to the mechanical action which has rounded the pebbles. Sharp-edged crystals of pyrites are also present, with which gold is intimately associated. The whole series is broken up by faults and igneous dykes, but it is not certain whether these influence the richness of the yield. Quartz veins, very rich in gold, occasionally traverse the conglomerates, and the steeper parts of the beds are richer

than the more horizontal portions. Fig. 57 shows these beds traversed by a reversed fault, which often causes an advantageous repetition of the gold-bearing strata. The conglomerates are evidently old beach deposits or gravels, since subjected to violent movements and permeated from below by auriferous solutions containing the cementing material, which explains the occurrence of the gold in the

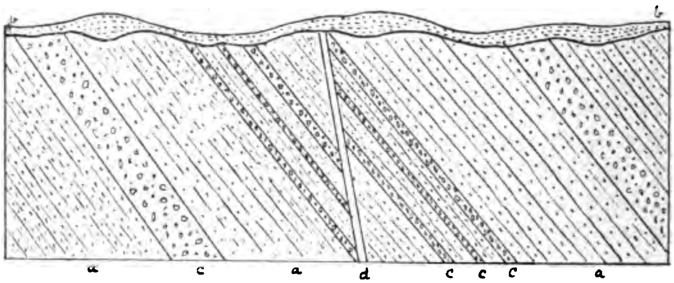

FIG. 57.

more permeable gravels rather than in the closer-grained sandstones. The infiltration was probably assisted in its upward passage by the fissures now marked by quartz veins, faults, or igneous dykes.

Many well-known facts go to prove that hot springs often contain a large proportion of metallic ingredients. Thus in Nevada numerous hot springs, marking lines of fissure, deposit a siliceous sinter containing notable quantities of gold, silver, lead, copper, zinc, mercury and other metals, some at least in the form of sulphides, sulphurous gases being also evolved in large quantities.

END OF PART I.

INDEX TO PART I

Butler & Tanner, The Selwood Printing Works, Frome, and London.